

FOR THE METAL, CERAMIC AND CARBIDE INJECTION MOULDING INDUSTRIES

Vol. 13 No. 2 JUNE 2019

# POWDER INJECTION MOULDING

## INTERNATIONAL



**in this issue**

**Low-pressure PIM review**  
**PIM at Hannover Messe**  
**Rapid prototyping solutions**

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For the metal, ceramic and carbide injection moulding industries

## MIM and AM: The convergence continues

The onward march of metal Binder Jetting continues. Following the announcement last September that MIM specialists GKN Sinter Metals and Parmatech were partnering with HP on the commercialisation of its Metal Jet process, industry giant Indo-MIM has now announced that it is partnering with Desktop Metal on high-volume Binder Jet Additive Manufacturing using the company's Production System.

The fact that so many in the MIM industry are embracing metal Binder Jetting will come as no surprise to regular readers of *PIM International*. Opportunities to take on projects which cannot be economically produced via a tool-based route, or that require a level of complexity that cannot be achieved by MIM, are clearly out there. The added attraction of being able to utilise existing furnace capacity also offers MIM producers a huge advantage over those entering AM from other industries.

As this issue highlights, Binder Jetting isn't the only 'PIM-like' AM process targeting our industry. Lithoz's Lithography-based Ceramic Manufacturing process and Xerion's Fusion Factory, based on Fused Filament Fabrication using filaments based on MIM and CIM feedstocks, also present opportunities for MIM companies.

What is becoming clear is that the oft-asked question, 'Which AM technology will win?', is misplaced. There will in the future be a multitude of dynamic technologies for the production of complex parts from metal and ceramic powders, each with its own advantages – and PIM will be one of them.

Nick Williams,  
Managing Director & Editor



### Cover image

MIM sensor housings produced by Sintex (Courtesy Sintex)



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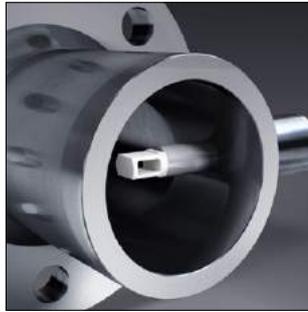
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The vast majority of metal and ceramic injection moulded parts are today produced on high-pressure injection moulding machines, operating at up to 200 MPa. However, Low-Pressure Powder Injection Moulding (LPIM), using pressures of up to 1 MPa, has been a focus of international development for a number of years. LPIM is now enjoying commercial success, driven partly by its ability to produce components at both low and high volumes, many of which are larger than can be produced by conventional PIM. Prof Vincent Demers outlines the current status of the technology and highlights the key technical differences between LPIM and conventional PIM.
  
- 65 The globalisation of the Powder Injection Moulding industry evident at Hannover Messe 2019**

For many decades, Hannover Messe has been the world's leading industrial exhibition. From April 1–5, 2019, more than 215,000 visitors viewed the exhibits of 6,500 companies from all over the world. Dr Georg Schlieper visited the show on behalf of *PIM International* and talked to the representatives of a number of PIM-related exhibitors on their booths. These interviews give some interesting insight into the current state of the industry.

- 75 Lithoz: How Lithography-based Ceramic AM is expanding the opportunities for technical ceramics**

Isabel Potestio, from Austria's Lithoz GmbH, reviews the Lithography-based Ceramic Manufacturing process, its parallels with CIM, and the opportunities that it presents for the ceramics industry.
  
- 83 Xerion's Fusion Factory: A complete production cell for prototype and one-off 'PIM-like' parts**

Dr Uwe Lohse, Xerion Berlin Laboratories GmbH, reports on a new modular 'PIM-like' AM system that offers PIM producers a technologically sophisticated solution to a long-standing sticking point for the industry – functional prototypes.
  
- 93 Dry ice cleaning in PIM: Theory, process and application**

Cold Jet LLC's Steve Wilson presents the advantages of using dry ice for mould cleaning. In addition to a reduced risk of wear or damage, environmental and economic and productivity-related benefits are outlined.

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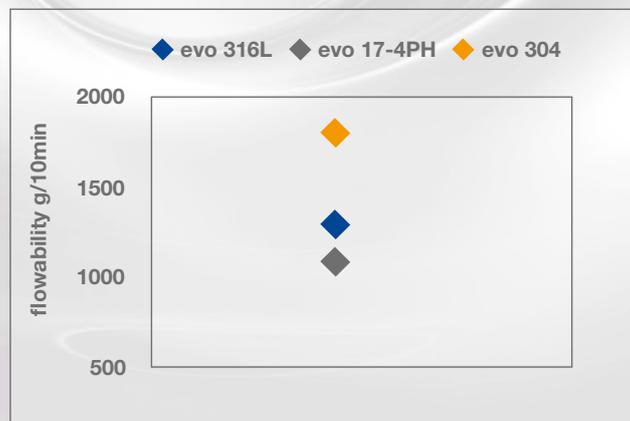
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# Industry News

## Indo-MIM announces partnership with Desktop Metal to scale-up metal Additive Manufacturing

Indo-US MIM Tec. Pvt. Ltd., a leading global Metal Injection Moulding company headquartered in Bangalore, India, has announced a strategic partnership with, Desktop Metal, Burlington, Massachusetts, USA. The agreement will see Indo-MIM become a full-service manufacturing partner for Desktop Metal, meeting the needs of customers looking for mass-produced metal parts in quantities ranging from tens of thousands to one million.

Indo-MIM has production facilities for metal injection moulded components in both India and the USA, as well as further sales offices in Europe and elsewhere in Asia. The company will deploy metal Additive Manufacturing at scale for its customers using Desktop Metal's Production System, to be installed at its San Antonio, Texas factory this summer.

In addition to its Additive Manufacturing capacity, Indo-MIM will also offer customers consulting services and finishing processes, key to entering the production phase.

"This is a major step forward in the progress of Additive Manufacturing," stated Krishna Chivukula, Jr., CEO of Indo-MIM. "As the world's largest MIM house, we know our customers in automotive, aerospace and other key industries will reap the benefits of this new mass manufacturing technology. We are excited to partner with Desktop Metal to bring metal AM closer to those companies looking to achieve the speed, cost, and quality benefits to their businesses."

"With the Production System now joining our state-of-the-art factories, we will be fully integrated to provide customers with a one-stop resource for the manufacturing of complex precision components

and sub-assemblies with Additive Manufacturing," he concluded.

The Production System is designed to build parts in a broad range of alloys, including reactive metals such as titanium and aluminium. Developed to take advantage of MIM's chemistry and powder supply chain, the Production System is said to offer access to a large and established ecosystem of high-quality alloys with a mature supply chain and well-studied controls.

"The synergies of our companies are profound – both Desktop Metal and Indo-MIM are deeply rooted in MIM technology, and we share an unbridled commitment to accelerate the availability of industrial Additive Manufacturing technologies," commented Ric Fulop, CEO and Co-founder of Desktop Metal. "This collaboration with Indo-MIM will help deliver the power and promise of our Production System to companies with diverse manufacturing needs and to shift the paradigm from prototyping to include full scale metal manufacturing."

[www.desktopmetal.com](http://www.desktopmetal.com) ■

[www.indo-mim.com](http://www.indo-mim.com) ■



Desktop Metal's Production System draws on the chemistry and existing material supply chain of the Metal Injection Moulding industry [Courtesy Desktop Metal]

## Thomas Weissgärber appointed provisional manager of Fraunhofer IFAM Dresden

Dr Thomas Weissgärber has taken over the provisional management of the Dresden branch of the Fraunhofer Institute for Manufacturing Technology (IFAM) and Advanced Materials IFAM. He succeeds Prof Bernd Kieback, who has retired after serving as head of the institute for many years. Dr Weissgärber, a long-time employee of the institute, previously served as deputy head of Fraunhofer IFAM Dresden, and has conducted research in various fields of Powder Metallurgy. He contributed significantly to the institute's development into one of the leading application-oriented research institutes in the field of PM technologies and materials.

He has also contributed to the strengthening of ties between science and applied research with lectures at the Technical University of Dresden on the topics of materials in energy technology, Powder Metallurgy and sintered materials, as well as thermophysical properties and high-temperature behaviour. In addition, he is involved in various committees in the field of PM.

By organising scientific events internationally, as well as at the Dresden location itself, he reportedly aims to contribute to the transfer of knowledge and the general perception of Powder Metallurgy, and to further strengthen and expand the location as a leader in PM. In November 2018, he was awarded the Skaupy Prize for his achievements to date at the Hagen Symposium.



*Dr Thomas Weissgärber has taken over the provisional management of the Dresden branch of the Fraunhofer IFAM*

Weissgärber stated that he sees his new role as motivation to continuously expand and build on existing competencies at Fraunhofer IFAM Dresden, and to utilise the institute's knowledge – especially in materials, PM and AM – for innovative, future-oriented solutions to generate optimal solutions in core areas such as energy technology, mobility and medical technology.

[www.ifam-dd.fraunhofer.de](http://www.ifam-dd.fraunhofer.de) ■

## Construction begins on Ceratizit's Reutte plant extension

Construction is now underway on an extension to Ceratizit Austria GmbH's manufacturing plant in Reutte, Austria. According to Ceratizit's parent organisation Plansee SE, the new build will be ready for occupation by spring 2022, and will house a staff of up to 300 workers.

The extension to the plant reportedly involves an investment in the double-digit million euro range, and the new facility is set to comprise a multi-storey building with a length of 200 m and width of 80 m; approximately twice the size of a football pitch. To combine the old plant with the new building, Ceratizit will pave a previously privately-used gravel road to route internal plant traffic away from public roads.

At present, three Plansee Group companies operate out of the same industrial park in Reutte. While Plansee SE manufactures semi-finished products and components made of tungsten and molybdenum metals, Ceratizit Austria specialises in the production of carbide tools for machining processes. The new building will house the Grinding Shop and Tool & Die, enabling Ceratizit Austria to meet the strong global demand for hard metal tools.

[www.ceratizit.com](http://www.ceratizit.com) | [www.plansee.com](http://www.plansee.com) ■

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## High demand for MIM hinges for foldable smartphones

According to Taiwan's *Digitimes*, the demand for MIM hinges for the next generation of foldable smartphones may outstrip production capacity in the near term. It was reported that sources at hinge makers have indicated that the tolerance for the high level of use that the hinges would be subjected to, compared to the MIM hinges in a lapbook computer, meant that they would need to be at least ten times stronger.

In addition, it was stated that the hinges used in foldable smartphones need to be thinner and more compact. For these reasons, the volume production of hinges may not be achievable until 2020. While smartphone vendors may adopt different folding technologies – for example in-folding designs by Samsung, out-folding by many of China's vendors, and a Z-folding method proposed by Google – the designs of the hinges themselves remain similar, said sources.

It was also stated that MIM hinge makers may have to increase their investments in furnaces to ramp up their capacity to meet demand. Taiwan-based hinge makers, including Shin Zu Shing (SZS) and Jarllytec, are reportedly targeting the foldable smartphone sectors.

[www.digitimes.com](http://www.digitimes.com) ■

## Boeing issued patent for binderless Metal Injection Moulding technology

The Boeing Company has been granted a US Patent (20150004047A1, filed September 2014) for what it describes as a binderless Metal Injection Moulding apparatus and method. The patent claims that, without the use of plastic binders, green metal injection moulded parts can be produced devoid of the residual binders found in the conventional MIM process, leading to better dimensional tolerances after sintering.

The patent claims that eliminating the debinding stage will make parts quicker and cheaper to produce than possible with conventional MIM. Although applications for the binderless MIM process are not specified, one of the aims of the process will undoubtedly be to produce components beyond the limitations of current debind/MIM technology, particularly in terms of size and shape.

The new binderless MIM process described in the patent application disclosure involves a fill hopper containing the metal powder, which feeds into an injection conduit linked to a two-part die set containing the die cavities. The powder being fed through the injection conduit is subjected to ultrasonic vibrations imparted by an ultrasonic transducer, which is in contact with the moulding die.

The vibrations are said to facilitate the 'fluid' flow of the powder particles into the die cavities in the two-part mould. The ultrasonic vibration of the MIM die is also said to compact the binderless powder to produce the required moulded green part. After moulding, the MIM die can be separated to remove the green parts, which can then be subjected to sintering and/or other post moulding steps. The patent application gives no indication of powder particle size or particle shape suitable for the binderless MIM process.

[www.boeing.com](http://www.boeing.com) ■

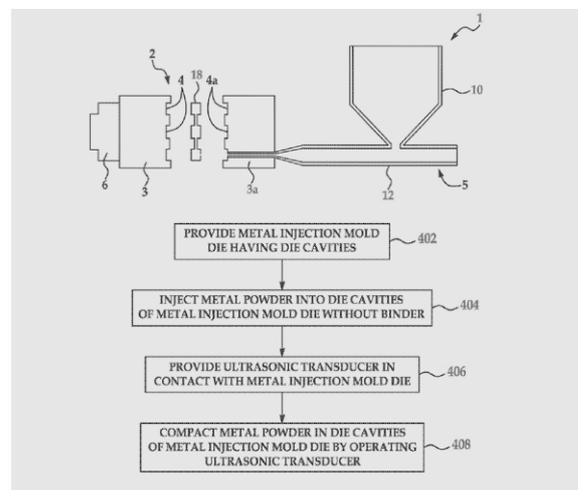
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A detail from Boeing's MIM patent (Courtesy Boeing)

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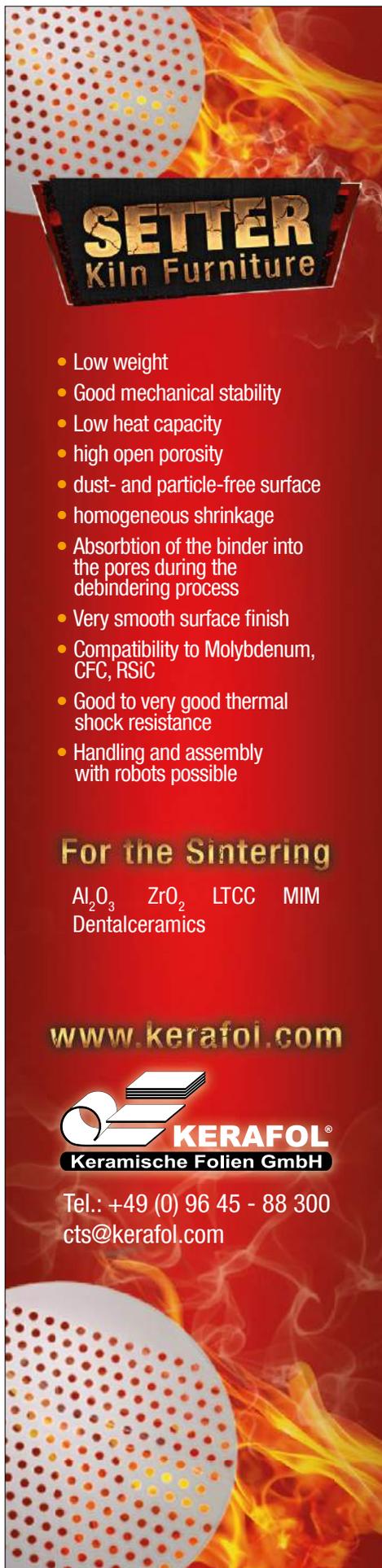
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## GKN Powder Metallurgy opens North American PM Headquarters and AM Customer Center

GKN Powder Metallurgy has opened its new North American Powder Metallurgy Headquarters and Additive Manufacturing Customer Center in Auburn Hills, Michigan, USA. The new facility will reportedly house over eighty employees from the three divisions of GKN Powder Metallurgy – GKN Hoeganaes, GKN Sinter Metals and GKN Additive – in a space the company states is designed to inspire teamwork and enhance customer experience.

The building includes a 3,200 ft<sup>2</sup> Additive Manufacturing Customer Center, equipped with two EOS M290 metal Laser Powder Bed Fusion (L-PBF) systems. EOS's systems are capable of manufacturing functional metal prototypes within a two-week lead time and allow customers to test factors such as usability, ergonomics, manufacturability and materials in the early stages of the development process. It is

expected that the full 38,260 ft<sup>2</sup> combined facility will expand the company's global Additive Manufacturing network and the scope of its in-house Powder Metallurgy capabilities.

Reid Southby, President of GKN Sinter Metals Large Segment, stated, "We are excited to start a new journey in Auburn Hills with a space that is dedicated to our team, our community and the advanced technology we create for our customers. This building reinforces our commitment to the North American market and continued global growth."

"GKN Powder Metallurgy is at an exhilarating point in its journey of growth and innovation," Southby continued. "We now have the opportunity to provide our customers and strategic partners with local and exceptional support on all fronts of our business."

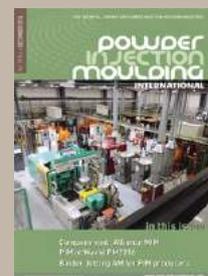
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GKN Powder Metallurgy opens North American PM Headquarters and AM Customer Center (Courtesy GKN Powder Metallurgy)

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## EPMA announces new President and Council Members

The European Powder Metallurgy Association (EPMA) has announced a number of leadership changes during its General Assembly 2019. The General Assembly took place at the Crowne Plaza Brussels – Le Palace Hotel, Brussels, March 21, 2019, and saw a number of EPMA Members gather to network and take part in the various Sectoral Group meetings, as well as discuss pertinent issues relating to the future of the PM industry and the association.

Every three years, the EPMA Statutes require an election to be held to form a new EPMA Council, as well as a new EPMA President and Treasurer (both subject to a maximum of two terms). The new EPMA Council was elected by a ballot of Full Member companies in advance of the General Assembly for the period of 2019–2022, with representatives of both Pometon

SpA and Polmo Lomianki SA joining the council for the first time.

As the tenure of the current EPMA President and Treasurer came to an end, the newly formed council announced during the General Assembly its choice for the EPMA's new President and Treasurer. Ralf Carlström, Digital Metal AB, was elected as EPMA President (2019–2022), succeeding Philippe Gundermann. Pierre Blanchard, Erasteel Kloster AB, was elected as EPMA Treasurer (2019–2022), succeeding Peter Kjeldsteen, Sintex A/S.

During the assembly, outgoing EPMA President Philippe Gundermann reported on PM industry trends and statistics, highlighting the various PM sectors. Lionel Aboussouan, the EPMA's Executive Director provided updates on the various EPMA

projects and activities undertaken by the association during 2018, and Kate Blackbourne, EPMA Congress Manager, gave insight into last year's Euro PM2018 Congress & Exhibition. Andrew Almond, EPMA Marketing Manager, provided an overview of marketing and promotional work in 2018 and the EPMA's new Technical Manager, Bruno Vicenzi, explained the various EU projects the EPMA has been involved with during the last twelve months.

Keynote speeches, presented towards the end of the assembly, saw Guy Thiran, Executive Director, Eurometaux, provide an update on 'Regulatory developments of interest to the Powder Metallurgy Industry', and Prof Thilo Bein, Fraunhofer LBF / Chairman for Materials, Design and Production Task Force, European Automotive Research Partners Association (EARPA), discuss 'Advanced Lightweight Design – Challenges and Trends'.

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## Sandvik Materials Technology to separate from the Sandvik Group

Sandvik AB, Stockholm, Sweden, is to initiate an internal separation of its business division Sandvik Materials Technology. The decision was made by Sandvik's Board of Directors with the reported aim of increasing the structural independence of Sandvik Materials Technology from the Sandvik Group. It is expected that this will put a significant focus on the business's future development possibilities, as well as creating flexibility. The Sandvik Materials Technology division includes Sandvik Opsrey, a leading international supplier of gas atomised powders for Metal Injection Moulding.

According to the company, the separation is expected to take at least a year, with no guarantee whether a decision to list Sandvik Materials Technology on the

Nasdaq Stockholm Exchange will be taken. "The decision to initiate an internal separation of Sandvik Materials Technology is based on the board's belief that each part will develop more favourably by itself, increasing opportunities for profitable growth and improving long-term shareholder value," stated Johan Molin, Chairman of the Sandvik Board of Directors.

"Sandvik Materials Technology represents the origin of Sandvik and great businesses have sprung out of it to shape the current structure. It is my view that a separation will allow full focus on Sandvik Materials Technology's key strengths and its further improved performance," commented Björn Rosengren, President and CEO of Sandvik.

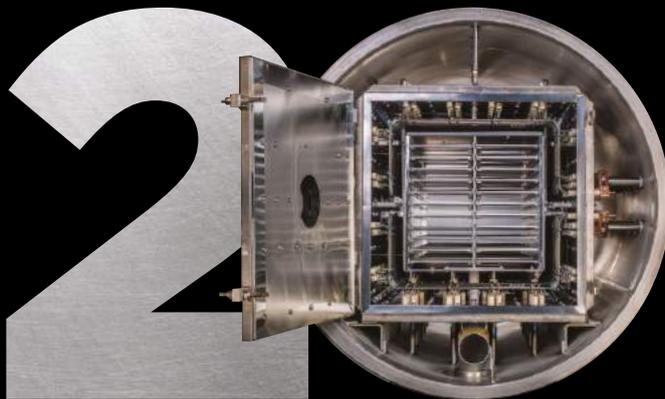
[www.home.sandvik](http://www.home.sandvik) ■

## EPHJ trade show on high-precision manufacturing draws near

The EPHJ-EPMT-SMT Trade Show (EPHJ) for the high-precision industry takes place from June 18–21, 2019, at Palexpo in Geneva, Switzerland. The event brings together the main high-precision industries of watchmaking and jewellery, microtechnologies and medical technologies under one roof.

Both metal AM and MIM have key applications in these areas and will feature in the exhibits and on the programme of presentations. This year's event marks the eighteenth edition of EPHJ-EPMT-SMT, and in 2018 saw 800 exhibitors and more than 20,000 visitors in attendance. The 2019 show is expected to host 120 more exhibitors than the prior year, each of which is exhibiting for the first time.

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## Aerojet Rocketdyne acquires 3DMT from MIM specialist ARC Group

Aerojet Rocketdyne Holdings, Inc., headquartered in El Segundo, California, USA, has acquired 3D Material Technologies (3DMT) from ARC Group Worldwide, Inc, whose operations include ARCMIM facilities in the US and Hungary. 3DMT, based in Daytona Beach, Florida, USA, is a provider of Additive Manufacturing services to the aerospace, defence, medical and industrial markets. Terms of the deal were not disclosed.

The acquisition is said to complement Aerojet Rocketdyne's industry-leading capabilities to develop and produce metal Additive Manufacturing parts for aerospace propulsion and power systems. Aerojet Rocketdyne has qualified production parts for the RL10 and RS-25 liquid rocket engines and sees growth opportunities for these complex, high-value systems. Additionally, the company's defence business unit continues to develop and demonstrate the benefits of Additive Manufacturing for its hypersonic propulsion systems.

"The addition of 3DMT's capacity and expertise in metal alloy Additive Manufacturing expands our range of products and services in the space and defence markets," stated Eileen Drake, CEO and President of Aerojet Rocketdyne Holdings, Inc. "As we look to the future, Additive Manufacturing will continue to play an important role in lowering costs and production timelines. This deal allows Aerojet Rocketdyne to broaden its application of this revolutionary technology. We respect the long-standing reputation for quality and customer focus that 3DMT has built in the aerospace industry and we are thrilled to welcome them to our company."

Aerojet Rocketdyne has more than 5,000 employees at fourteen sites around the USA, including approximately 650 employees at its facilities in West Palm Beach and Orlando, Florida. 3DMT will continue to operate with its existing workforce at its 2600 m<sup>2</sup> (28,000 ft<sup>2</sup>) facility located in Daytona Beach, Florida.

[www.aerjetrocketdyne.com](http://www.aerjetrocketdyne.com)

[www.3dmt.com](http://www.3dmt.com) ■



3DMT is a leading Additive Manufacturing service provider specialising in complex technical components (Courtesy 3DMT)

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system solutions



## Melrose reports no immediate plans to offload GKN Powder Metallurgy

Melrose Industries PLC, UK, has reported that despite earlier plans for a quick sale of the GKN Powder Metallurgy division, the company has no immediate plans to sell the business. In the company's 2018 Annual Report, Melrose stated that, "whilst we will continue to review the position in the months to come, we expect

GKN Powder Metallurgy to remain in the group for the present."

Upon taking control of GKN, Melrose stated that it set about removing the duplicate central functions and decentralising the GKN businesses, simultaneously reorganising the Melrose Group into five divisions: GKN Aerospace; GKN

Automotive; GKN Powder Metallurgy; Nortek Air & Security; and Other Industrial.

"For the GKN businesses, decentralisation was the first step in bringing about the change in culture we believe is vital to securing long-term improvement," stated Simon Peckham, Melrose's Chief Executive. "For GKN Aerospace and GKN Powder Metallurgy, we worked with incumbent management teams to agree their management plans."

"Having agreed their approach, the GKN businesses have been given the freedom and responsibility to start to deliver on their commitments. Part of this has been a refocus on profitable sales rather than solely on growth. There is also a clear expectation that they be good stewards of their businesses for the benefit of all stakeholders."

In the Annual Report for the year ended December 31, 2018, the company announced statutory revenue for the Melrose group of £8,605 million (2017: £2,092 million) and, despite declaring a statutory operating loss of £392 million (2017: £7 million), primarily as a result of the required accounting for the GKN acquisition, its adjusted operating profit was £847 million (2017: £279 million).

"This has been a transformational year for Melrose and we are delighted to announce, on an annualised adjusted basis, an operating profit of over one billion pounds. The former GKN businesses are proving their potential to offer the outstanding opportunities we expected and much has already been achieved in the short period of ownership," stated Justin Dowley, Melrose's Non-executive Chairman.

"Despite the current economically uncertain environment, we have every confidence that we will be able to continue to unlock the substantial shareholder value from the former GKN businesses and further improve Nortek," he concluded.

[www.melroseplc.net](http://www.melroseplc.net) ■

The advertisement features a woman with long red hair, wearing a blue denim jacket, looking upwards with a smile. The background is a light blue and white geometric pattern. At the top, the logos for Wittmann and Battenfeld are displayed in white on a dark blue background. Below the woman, the text "enjoy INNOVATION" is written in a stylized font, with "enjoy" in blue and "INNOVATION" in red. In the bottom left corner, the text "Wittmann 4.0 plug & produce" is shown. The bottom right corner features a large image of a blue industrial machine with a control panel. Red lines connect various components of the machinery to the machine's interface. At the bottom, the website address "www.wittmann-group.com" is displayed in white on a dark blue background.

## ExOne reveals new X1 25PRO metal AM system and announces Kennametal as beta customer

The ExOne Company, a provider of Additive Manufacturing systems and services, headquartered in North Huntingdon, Pennsylvania, USA, revealed its new X1 25PRO™ metal Additive Manufacturing beta system at Rapid + TCT 2019, Detroit, Michigan, USA. The company also announced Kennametal Inc., a supplier of tooling and wear resistant solutions, located in Latrobe, Pennsylvania, USA, as a beta customer.

During the beta period, ExOne states that Kennametal will have the opportunity to evaluate the X1 25PRO system and trial new materials and processes. According to ExOne, the high-resolution production machine is capable of additively manufacturing metal, ceramic, and other advanced material parts directly, as well as

standard industry powders utilised in Metal Injection Moulding and other Powder Metallurgy (PM) processes.

“We see Binder Jet technology as a key enabler for our differentiated, high-performance wear materials, such as tungsten carbide and Kennametal Stellite™ alloys,” stated Sherri McCleary, Director of Business Development Additive at Kennametal. “Kennametal is uniquely qualified to supply these additive materials and components, and we’re pleased to collaborate with ExOne on cutting-edge technology with the potential to help us advance from prototyping to serial production.”

John Hartner, Chief Executive Officer at ExOne, commented, “Working with innovative, global companies like Kennametal is



The ExOne Company revealed its new X125PRO beta system at Rapid + TCT 2019 (Courtesy ExOne)

another important step towards integrating industrial 3D printing into existing and new production lines. We are excited to bring Kennametal on as a beta user and look forward to beginning the testing programme.”

[www.exone.com](http://www.exone.com)

[www.kennametal.com](http://www.kennametal.com) ■

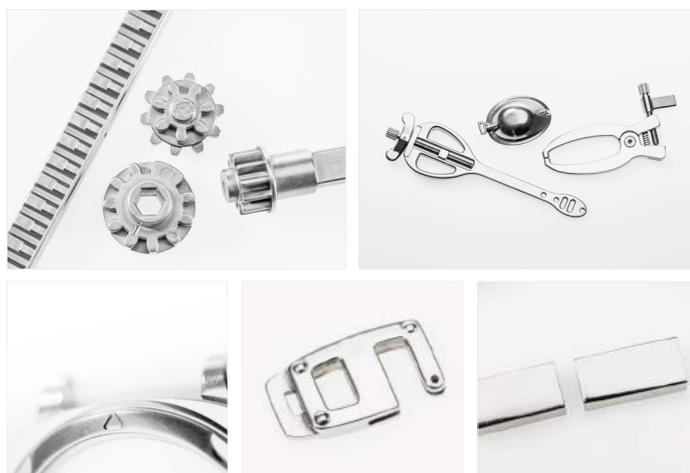


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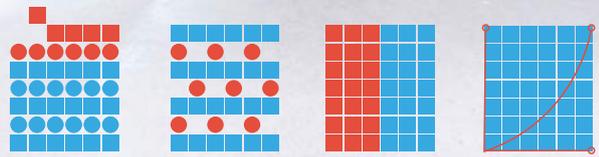
[matrix-mim.com](http://matrix-mim.com)

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[xerion.de/fusionfactory](http://xerion.de/fusionfactory)

## Krahn Chemie acquires eMBe Products & Service to expand MIM and CIM capabilities

Krahn Chemie GmbH, a chemical distribution company, headquartered in Hamburg, Germany, has acquired eMBe Products & Service GmbH, Thierhaupten, Germany. eMBe Products & Service was founded in 2007 and produces binder systems for MIM and CIM and MIM feedstocks. As well as offering customised product solutions, the company states that it is also possible to supply materials in small quantities. The products made by eMBe are marketed under the trade names of Embemould® and Embelube®. Krahn Chemie states that the acquisition came into effect on May 1, 2019.

Axel Sebbesse, Managing Director of Krahn Chemie GmbH, commented, "The acquisition of eMBe is closely linked with our strategy of supporting customers in a targeted fashion in all stages of their production processes, from the raw material to the end product. Krahn has been active in technical ceramics for more than twenty-five years now and has made a special contribution to the development of this market in the dental field. We are now going a step further and bundling our competence with the technical know-how of eMBe in order to be able to address the wishes of customers even more individually and also convince companies that don't yet use ceramics of the advantages of this material. This is because ceramics are, and remain, materials with a future, the application portfolio of which is still far from being exhausted."

[www.krahn.eu](http://www.krahn.eu) | [www.embe-products.com](http://www.embe-products.com) ■

## Second International Symposium on Innovation in Materials Processing 2019 to take place in Korea

A call for papers has been issued for the second International Symposium on Innovation in Materials Processing (ISIMP), which is organised by the Korean Powder Metallurgy Institute, Seoul, Korea, and the Korean Institute of Metal and Materials, Seoul, Korea, and will take place at the Phoenix Jeju Hotel in Jeju, Korea, from November 6–8, 2019.

Authors are invited to submit abstracts by September 16, 2019; those selected will be expected to submit their full papers by November 18, 2019. ISIMP 2019 will bring together leading scientists, researchers, engineers, practitioners, technology developers and policy makers in the materials processing industry for networking opportunities and to discuss the latest developments in research and innovation.

[www.isimp.org](http://www.isimp.org) ■

## HP's new global network for AM production includes Parmatech and GKN

HP Inc. has announced the launch of its new HP Digital Manufacturing Network, described as a global network of HP production partners which will help design, produce, and deliver both polymer and metal additively manufactured parts at scale. The network is expected to enable customers to speed the development of new products, shorten time to market, create leaner supply chains and reduce their carbon footprint.

The HP Digital Manufacturing Network initially includes partners in the United States, Asia, and Europe. The company stated that it will further expand the network into other target markets with additional qualified partners in the coming months.

Initial partners include GKN Powder Metallurgy, Parmatech, Materialise, Forecast 3D, GoProto,

Jabil and ZiggZagg NV. Each partner will use HP's Additive Manufacturing solutions and draw on their own Additive Manufacturing expertise, high-volume production capacity and end-to-end manufacturing processes to meet customer needs.

Fried Vancaeren, Founder and CEO, Materialise, commented on the network's launch, "Our customers are excited by our tighter integration with HP, our joint work on new applications and materials, and our commitment to scale high-quality part production. Together we are helping our customers win in an increasingly competitive marketplace."

"The Fourth Industrial Revolution is one of the most transformative forces in our lifetime. New technology innovations will be required, new partnership models will emerge,



HP's Metal Jet system can produce high volumes of parts, with a Binder Jetting build size of 430 x 320 x 200 mm (Courtesy HP)

and new modes of doing business will unfold," stated Christoph Schell, President of 3D Printing and Digital Manufacturing, HP. "HP is committed to helping customers with diverse manufacturing needs turn change into opportunity by delivering the most innovative solutions portfolio and comprehensive ecosystem of industry-leading partners."

[www.hp.com/go/DigitalManufacturingNetwork](http://www.hp.com/go/DigitalManufacturingNetwork) ■



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## MIM2020 international conference returns to Irvine, California, next March

MIM2020, The International Conference on Injection Molding of Metals, Ceramics and Carbides, will be held in Irvine, California, USA, from March 2-4, 2020. MIM2020 is a global conference and tabletop exhibition that highlights advances in the metal and Ceramic Injection Moulding industries.

The annual conference is sponsored by the Metal Injection Molding Association (MIMA), a trade association of the Metal Powder Industries Federation (MPIF) and its affiliate APMI International.

The 2020 conference will be chaired by Michael Wiseman, ARC Group Worldwide, and Tom Pelletiers, Kymera International. A call for papers has been issued, with an abstract submission deadline of October 4, 2019.

The event returns to Hotel Irvine and highlights are set to include:

- A full conference programme of both high-level technical research and commercially-oriented presentations
- Tabletop Exhibition & Networking Reception
- The annual PIM Tutorial, presented by industry veteran Randall M German

This year's MIM2019 welcomed more than 150 attendees, representing ninety-five companies from fifteen countries. The event once again saw a significant number of delegates from the metal AM industry, in particular those with a focus on the 'MIM-like' Binder Jetting and FFF processes.

[www.mim2020.org](http://www.mim2020.org) ■

## Nabertherm appoints Timm Grotheer its new Managing Director

Nabertherm GmbH, Bremen, Germany, has announced the appointment of Timm Grotheer as its new Managing Director. Grotheer, who previously served as Managing Director of shipbuilding group Lürssen, succeeds Friedrich-Wilhelm Wentrot, who has served as Managing Director of the company for eighteen years. Under Wentrot's direction, Nabertherm reported that it has seen global success, employing more than 500 staff and achieving a turnover of more than €60 million (\$68 million). A key element in Wentrot's strategy has been the internationalisation of the business, which now exports 70% of its furnaces and plants.

[www.nabertherm.com](http://www.nabertherm.com) ■

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## Wittman Group reports continued growth in fiscal year 2018, anticipates slowdown

Injection moulding machine producer Wittmann Group, headquartered in Kottlingbrunn, Austria, reports that it achieved increased sales figures in 2018 compared to the previous year, thus continuing its trend of year-on-year growth. However, the company also noted that since the end of 2018, it has seen a slowdown in orders.

In 2018, the group achieved sales of €425 million, representing an increase of just under 6% in turnover compared to the previous year. Highlights of the fiscal year 2018 for the company included the completion of extensive building projects, adding 2,200 m<sup>2</sup> to its overall production area. New administrative facilities were also built, which significantly expanded the available office space. Also constructed was a new R&D lab. On the production floor, the company completed installation of assembly lines for its EcoPower and SmartPower from 1,800 kN upwards.

In addition to the extensions in Kottlingbrunn, Wittmann's facilities in Nuremberg, the Czech Republic, Mexico and Italy were also expanded. The construction of a new, larger building in France, which was started in 2018, has also now been completed. The company moved into its new facilities at the end of April this year.

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The extensive activities of the Wittmann Group relating to Industry 4.0 were supplemented in September 2018 with its acquisition of a stake in the Italian Manufacturing Execution System (MES) producer ICE-flex. As a result, the group's 'Wittmann 4.0' technologies can now be integrated more smoothly into the TEMI+ MES program.

Fiscal year 2019 began for the group with an order income on a par with 2016. Michael Wittmann, CEO,

commented, "Innumerable political and economic uncertainties and discussions are now finally having a lasting effect on the investment behaviour in our industry, slowing it down. We were fully aware of the fact that the incredible succession of record results over the last ten years would eventually come to an end. The slowdown has now just started in the last quarter of 2018. We expect that the year 2019 will continue on the current level."

[www.wittmann-group.com](http://www.wittmann-group.com) ■



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[www.loemi.com](http://www.loemi.com)

## BASF 3D Printing Solutions appoints Chief Commercial Officer

BASF 3D Printing Solutions GmbH, located in Heidelberg, Germany, a wholly-owned subsidiary of BASF New Business GmbH, has appointed François Minec as its Chief Commercial Officer. In his new role, Minec will be responsible for the commercial development of all four BASF 3D Printing Solutions business segments.

Minec reportedly has over fifteen years experience of business development in specialty plastics and chemicals, and previously founded the company Advanc3D Materials, which specialised in material solutions for Powder Bed Fusion Additive Manufacturing.

"With François Minec, we have gained a proven industry expert for this key role, François has extensive knowledge and experience in the dynamic market of industrial 3D printing. Together with him, I am pleased to continue our consistent growth trajectory," commented Volker Hammes, who is responsible for the business development of BASF 3D Printing Solutions.

BASF 3D Printing Solutions is made up of startup-like structures designed to serve customers in the Additive Manufacturing market. It cooperates closely with the global research platforms and application technologies of various departments



*BASF 3D Printing Solutions has appointed François Minec its Chief Commercial Officer*

at BASF, and with research institutes, universities, startups and industrial partners.

[www.basf-3dps.com](http://www.basf-3dps.com) ■

## Second Edition of 'Handbook of Metal Injection Molding' published

The Second Edition of the 'Handbook of Metal Injection Molding' provides an updated and authoritative guide to MIM technology and its applications. Building on the success of the First Edition, this update includes the latest developments in the field and expands upon specific processing technologies. Donald F Heaney, the book's editor, is President and CEO of Advanced Powder Products, Inc., Philipsburg, Pennsylvania, USA, and Director of the Center for Innovative Sintered Products at Pennsylvania State University.

Much like the First Edition, the 656-page Second Edition is divided into four main sections but now offers updated technologies and processes for the MIM industry. Part one of the handbook offers a comprehensive review of 'Processing', which includes key criteria for designing MIM components, powders for MIM, powder binder formulation and compounding, commercially available feedstocks, tooling, moulding of components, and debinding and sintering methods.

Part two covers 'Quality issues' in Metal Injection Moulding, which include the characterisation of feedstock, modelling and simulation, common defects, qualification, and the control of carbon content. Part three discusses 'Special metal injection moulding processes'; micro Metal Injection Moulding (Micro-MIM), automation of the MIM process, two-material/two-colour Powder Injection Moulding (2C-PIM), Powder Space Holder MIM (PSH-MIM), micro-porous metals and the MIM of large components.

The final section explores the Metal Injection Moulding of specific materials, including stainless steels, titanium and titanium alloys, thermal management materials in microelectronics, soft magnetic materials, high-speed tool steels, heavy alloys, refractory metals, and hard metals, superalloys, carbon steel, precious metals and aluminium.

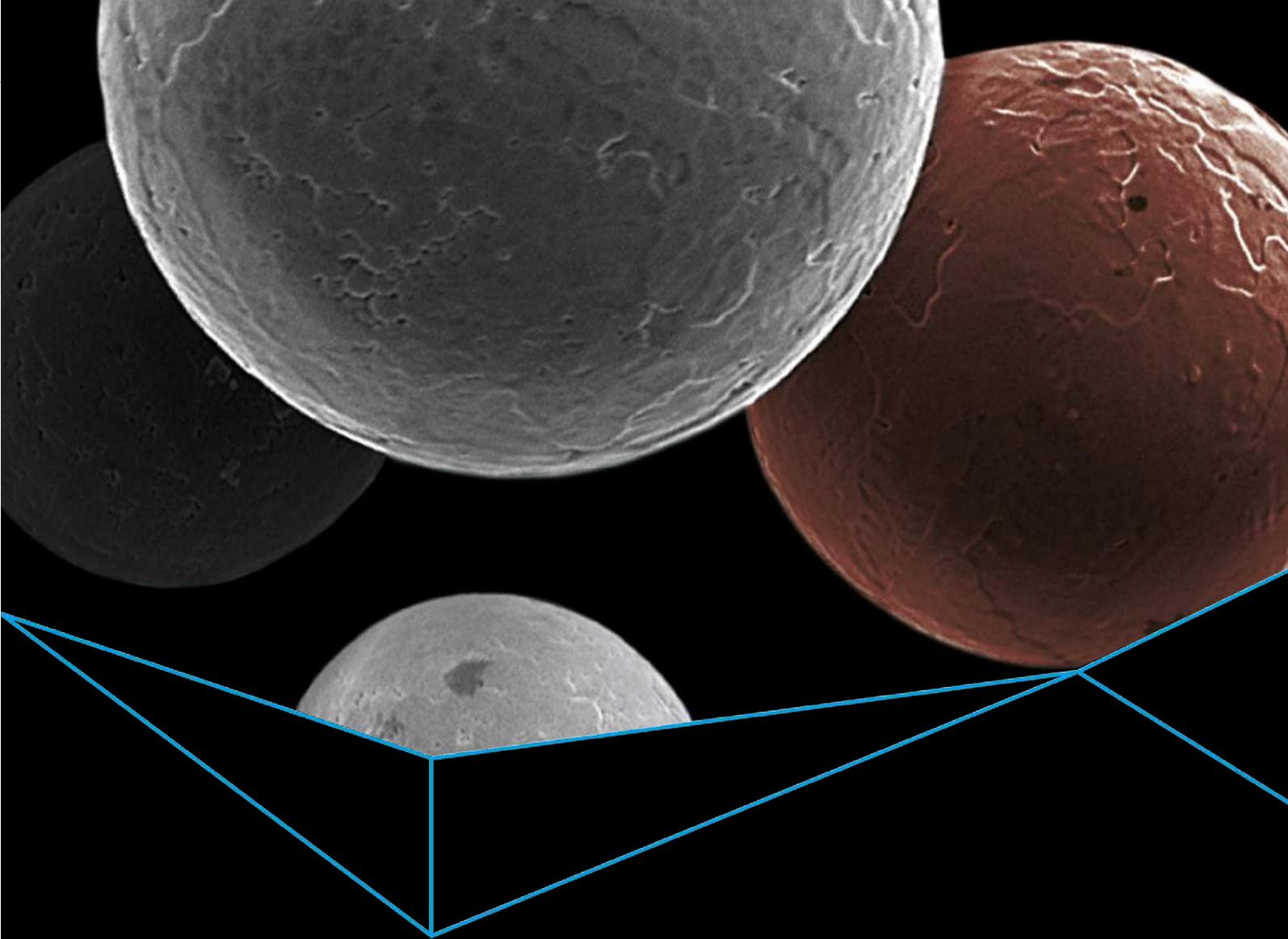
[www.woodheadpublishing.com](http://www.woodheadpublishing.com) ■

## Bodycote invests in new US heat treatment facility

Bodycote plc, a global provider of heat treatment and specialist thermal processing services headquartered in Macclesfield, UK, is expanding its capabilities in North America with the launch of a new heat treating facility in Elgin, Illinois, USA. According to the company, the new facility will offer advanced heat treating technologies such as low-pressure carburising and carbonitriding, vacuum nitriding and ferritic nitrocarburising, Bodycote's Corr-I-Dur® process, and traditional carburising of large parts.

Operating from more than 180 accredited facilities in twenty-three countries, Bodycote provides classical heat treatment and specialist technologies including Hot Isostatic Pressing (HIP) to a wide range of industries, including aerospace, defence, automotive, power generation, oil & gas, construction, medical and transportation. The new facility is expected to be operational by late 2019.

[www.bodycote.com](http://www.bodycote.com) ■



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## Successful PM China 2019 concludes in Shanghai

The 12<sup>th</sup> Shanghai International Exhibition for Powder Metallurgy, Cemented Carbides and Advanced Ceramics (PM China 2019) ran successfully at the Shanghai World Expo & Convention Center, China, from March 25–27, 2019. The organisers, Uniris Exhibition Shanghai Co Ltd, reported that the exhibition hosted 464 exhibitors, an increase of 11% over the previous edition, and welcomed 22,637 visitors across the four days of the event, a growth of 19.5% over last year. As in previous years, China's Metal Injection Moulding industry was prominently represented.

A number of visiting delegations were also organised to participate in the event, including the Delegation of Advanced Ceramics Industry, Study Group of Korean Advanced Ceramics Industry, Delegation of China's Advanced Ceramics Industrial Alliance, Delegation of Jiangsu Ceramic Society and the Ceramics and Refractory Materials Committee.

Exhibiting companies were present from a large number of countries including China, the USA, Germany, the UK, Italy, France, the Netherlands, Sweden, Switzerland, Austria, Russia, Canada, Japan, South Korea, Poland, Singapore, India, Hong Kong and Taiwan, covering various fields such as powder raw materials, products, mechanical equipment, Additive Manufacturing, testing instruments, gas and process solutions. Approximately 210 equipment companies, accounting for 45% of exhibitors, exhibited at the show, as well as about 114 material companies, accounting for 24%; approximately 120 product companies, accounting for 26%; and approximately twenty Additive Manufacturing companies, accounting for 5%.

A number of academic forums and exchange meetings were also held at the show, including the 2019 China Summit Forum on Cutting-



A 25,000 m<sup>2</sup> exhibition area represented a 12% rise over the previous year

edge Technology Application and Development in Advanced Ceramic Industry & Academic Annual Meeting of the Industrial Ceramics Committee of Chinese Ceramic Society, The 8<sup>th</sup> Shanghai International Injection Moulding Forum, the Academic Annual Meeting of China Powder Metallurgy Alliance & 2019 Shanghai International Powder Metallurgy Forum, and more.

The 13<sup>th</sup> Shanghai International Exhibition for Powder Metallurgy, Cemented Carbides and Advanced Ceramics will be held at the Shanghai World Expo & Convention Center from March 24–26, 2020.

[www.en.pmxchina.com](http://www.en.pmxchina.com) ■

## Formnext + PM South China: A new trade show for MIM, AM and PM

The first ever Formnext + PM South China trade show for the Additive Manufacturing and Powder Metallurgy industries will be held in Shenzhen, China, from September 9–11, 2020. Organised by Mesago Messe Frankfurt GmbH, Germany, Guangzhou Guangya Messe Frankfurt Co Ltd, China and Uniris Exhibition Shanghai Co Ltd, China, the new trade show will showcase the metal powder industries to an international audience.

Petra Haarbuerger, Managing Director of Mesago Messe, the organiser of the annual Formnext show in Frankfurt, stated, "Formnext + PM South China offers both Chinese and international additive manufacturers an exceptional platform in the highly dynamic southern China region." The

Greater Bay Area around Shenzhen is said to be a key location for innovation in science, technology, electronics, manufacturing, automotive manufacturing, robotics and automation in China, and a major driver for the economy.

According to Sascha Wenzler, Vice President for Formnext at Mesago Messe, "Formnext has been a resounding success in Europe and we are confident that the combination of Additive Manufacturing, materials, and innovative process technologies will also perfectly address the current and future needs of the Chinese manufacturing industry."

Uniris Exhibition Shanghai Co Ltd previously organised the Powder Metallurgy Expo South China. With the support of Messe Frankfurt's

extensive global network of branch and sales offices, it was stated that the new trade show will be widely promoted on relevant national and international media channels, online portals and social media. Exhibitors are also expected to benefit from Uniris' experience in markets related to the PM industry.

Formnext + PM South China will target visitors from a wide range of sectors, including architecture, automation, automotive, aerospace, construction, dental technology, home appliances, electrical engineering and electronics, packaging technology, medical technology and toolmaking. The event will be held at the Shenzhen World Exhibition and Convention Center, which is currently under construction and which, when completed, is expected to be one of the largest exhibition centres in the world.

[www.messefrankfurt.com](http://www.messefrankfurt.com) ■

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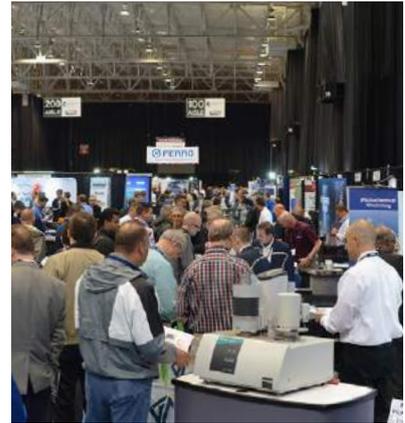
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## Ceramics Expo reports a positive response to its fifth event

Ceramics Expo 2019 was held at the I-X Center in Cleveland, Ohio, USA, from April 30–May 1, 2019. This marked the fifth edition in the event series, which is organised by Smarter Shows, Brighton, UK. The organisers reported a positive response to the event's new two-day format, as well as newly-added features such as a pre-show VIP reception and networking event.

The exhibition hosted the complete ceramics supply chain, including raw material suppliers, equipment manufacturers and ceramics producers. Featured companies included CoorsTek, Corning, Morgan Advanced Materials, Kyocera, Schott and Saint-Gobain. A Product Showcase featured live demonstrations of new machinery, testing services and analysis equipment from exhibitors



Over 2,800 visitors attended Ceramics Expo 2019

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which included 3DCeram Sinto, Beckman Coulter, OptiPro Systems and The Model Shop.

Held concurrently with the exhibition, the Ceramics Expo Conference presented sessions exploring future trends, manufacturing practices and developments from the ceramic and glass industry. The agenda was reportedly designed for engineers and decision makers in the automotive, aerospace/defence, medical, electronics, industrial, energy and communication industries. Companies who spoke at the conference included Lockheed Martin, Ford Motor Company, NASA, General Electric Aviation and Oak Ridge National Laboratory. This year, Ceramics Expo welcomed over 2,800 attendees and 300 exhibiting companies from thirty-five countries.

"It's been awesome," stated Mano Manoharan, Chief Technologist, Ceramic Composites and Coatings, GE Additive. "I think I came for the first time about five years ago and I think it has grown quite a bit since then, because I don't remember as many aisles when I last came. So, I think every year it gets bigger. I think it's also a larger range of participation - I see some academic people, a lot of industrial participation."

Ceramics Expo has announced that next year's exhibition and conference will again be held in Cleveland, Ohio, USA, from May 5–6, 2020.

[www.ceramicsexpousa.com](http://www.ceramicsexpousa.com) ■

## Arcast metal powders certified for commercial, aerospace & defence industries, new Ti superalloy powder

Arcast Inc. and Arcast Materials Division, Oxford, Maine, USA, have achieved certification to ISO 9001:2015 and AS9100D for the manufacture and sale of metal powder and castings for commercial, aerospace and defence applications. Arcast stated that it built its new materials division around these quality management systems to ensure its ability to meet the industry's most demanding requirements.

The new certification means that Arcast's metal powders, as well as its casting products, can now be sold to a wide range of markets, including aerospace, with the confidence that it can meet the quality standards required by its customers. With its growing capacity to produce

as-atomised titanium alloys (along with other challenging metal alloys) with a D50 of 30-40 µm from a range of low-cost feedstock, Arcast states that it can offer a complete solution for Additive Manufacturing, Metal Injection Moulding and other Powder Metallurgy markets.

"Our ultra-clean and high-performing processing method offers the highest possible quality powder and is now backed up by a quality standard that matches it," commented Sasha Long, Arcast Vice President.

Arcast has also reported that it has successfully produced a titanium superalloy powder with an as-atomised D50 of 20 µm, with narrow size distribution and with little-to-no oxygen pick-up. The

alloy was produced using Arcast's proprietary atomising process.

Arcast's process, it was stated, consumes relatively little gas and has zero risk of ceramic/oxide contamination, the company states, making it possible to process metal alloys which other methods cannot. Powders produced by this method can be used in Additive Manufacturing, Metal Injection Moulding and other Powder Metallurgy processes. The production of powder by this process also does not require specialist feedstock.

Arcast stated that the new alloy is now being produced in significant quantities. With its growing capacity to produce as-atomised, advanced titanium alloys (along with other challenging metal alloys) from a range of low-cost feedstock, Arcast states that it can offer a complete solution for Additive Manufacturing, Metal Injection Moulding and other Powder Metallurgy markets.

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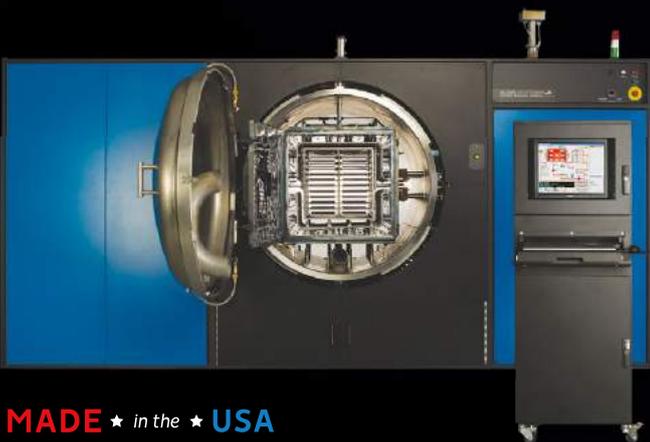
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## Mimete begins metal powder production at its Italian facility

Mimete S.r.l., Osnago, Italy, a division of the Fomas Group, Osnago, Italy, has started to produce metal powders from its new and customised VIGA (Vacuum Inert Gas Atomisation) facility. Mimete's manufacturing plant has been specifically designed by Fomas to supply AM and MIM grade powders and will target various sectors, primarily biomedical, power generation, aerospace and racing.

According to Mimete, the first atomisation process was monitored through an advanced production management system and the alloy chosen for the first batch of powder was 316L. Production of In625 and F75 is currently ongoing. The company stated that it then analysed the powders at its in-house laboratory, which it expects to be accredited to EN ISO IEC 17025 in the near future. Scanning Electron Microscope (SEM) images of the powder produced reportedly showed a morphology that was spherical and homogeneous, and the measured flowability also met the targets set.

Maria Guzzoni, Mimete Strategy & Special Projects Co-ordinator, stated, "We were all very excited to be together for the first atomisation. It was not about scoring the best result, but it was more about getting to the end of the cycle – the starting point for future challenges and improvements. We studied a lot and we were well prepared for all scenarios, but we were aware that moving from theory to reality always implies a certain level of uncertainty. We were incredibly moved to finally see the successful results of all the hard work and the commitment we went through last year."

[www.mimete.com](http://www.mimete.com)

[www.fomasgroup.com](http://www.fomasgroup.com) ■



Mimete, a division of the Fomas Group, starts production of metal powders from its manufacturing plant in Italy (Courtesy Fomas Group)

## MicroCare debinding fluids showcased at Ceramics Expo

During Ceramics Expo 2019, held in Cleveland, Ohio, USA, from April 30–May 1, MicroCare, New Britain, Connecticut, USA, showcased its expanding range of debinding fluids, including its Tergo™ MCF performance fluid. Tergo MCF performance fluid reportedly has excellent solvency with low viscosity and surface tension, and a low boiling point. This means that PEG, paraffin or other binders are selectively removed without having a negative impact on the dimensional stability of parts when they are sintered. It also enables shorter sintering times, which accelerates throughput and overall productivity.

MicroCare described Tergo MCF as a 'new generation' vapour degreasing fluid for cleaning parts through solvent immersion technology, as well as an effective debinder for MIM, CIM and AM. Rob Lee, Senior Market & Technical Manager at MicroCare, commented, "We are receiving many enquiries for functional fluids to help debind parts made through Ceramic Injection Moulding, Metal Injection Moulding and Additive Manufacturing. Tergo MCF is just one of the products from MicroCare that is helping to expedite this process."

[www.precisioncleaners.microcare.com](http://www.precisioncleaners.microcare.com) ■

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## Desktop Metal increases production of its Studio Systems

Desktop Metal, Burlington, Massachusetts, USA, has increased the production of its Studio Systems. The company is now reportedly shipping at a rate of 550 complete systems per year, with a two-week delivery time for new orders to customers throughout the USA and Canada.

The Studio System is reportedly designed to make metal Additive Manufacturing more accessible, enabling design and engineering teams to additively manufacture metal parts faster, without the need for special facilities, dedicated operators or expensive tooling. The three-part solution, including printer, debinder and furnace, automates metal AM by tightly integrating through Desktop Metal's cloud-based software to deliver a seamless workflow for additively manufacturing complex metal parts in-house, from digital file to sintered part.

According to Desktop Metal, over a period of six months, Studio Systems have been used to produce more than 8,000 parts globally. Key use applications reportedly include functional prototyping of extruder nozzles and shock absorber pistons; jigs and fixtures including robotic



Desktop Metal's Studio System (Courtesy Desktop Metal)

end effectors and break calliper fixtures; manufacturing tooling of zipper moulds inserts and extrusion dies; and low-volume production of gears and motor mounts. Each of these benchmark parts has reportedly shown a reduction in cost, some by as much as 90% relative to machining and Laser Powder Bed Fusion (L-PBF), as well as speed, which enables the company to reportedly produce parts in days rather than weeks or months.

Customers of the Studio System include Ford, Stanley Black and Decker, Goodyear, 3M, Google's ATAP, BMW, ProtoLabs, Owens Corning, L3, TerraPower, Medtronic, Continental AG, Applied Materials, TECT Aerospace, US Department of Defense, Department of Homeland Security, MITRE and leading educational institutions such as MIT, University of Texas, Texas A&M and Diman Regional Vocational Technical High School, said to be the first high school in the USA to install a metal Additive Manufacturing system.

Ric Fulop, CEO and Co-founder of Desktop Metal, stated, "Leading companies, such as Ford, Google's ATAP, Goodyear, BMW, and ProtoLabs, are now benefiting from the ease of use and accessibility provided by the Studio System. To meet continued demand, we have scaled up production capacity to allow us to deliver complete systems for fast installation."

[www.desktopmetal.com](http://www.desktopmetal.com) ■



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## Hanser Fachbuch to publish book dedicated to micro injection moulding

Hanser Fachbuch is set to publish '*Micro Injection Molding*', a book dedicated exclusively to micro injection moulding, including MicroPIM, and overcoming the challenges of managing and processing materials at ultra-small scales.

The 408-page book reportedly provides engineers, project managers, researchers, consultants and other professionals involved in precision micro-manufacturing with a comprehensive, up-to-date and detailed treatment of the main topics related to micro-moulding, from material and process technology to tooling, to key-enabling technologies, and multi-material process variations.

Guido Tosello, the book's author, is an Associate Professor at the Technical University of Denmark's Department of Mechanical Engineering. His principal research interests include the analysis, characterisation, monitoring, control, optimisation and simulation of precision moulding processes at micro/nano scales.

Tosello divides '*Micro Injection Molding*' into four sections, with the aim of delivering a full analysis of the micro injection moulding industry. Part one covers 'Polymer Materials and Process Micro Technology' - micro injection moulding machine technology; micro-moulding process monitoring and control; polymer materials structure and properties in micro injection moulding parts; and surface replication in micro injection moulding. Part two explores 'Tooling Technologies for Micro Mold Making' - micro-machining technologies for micro injection mould making; ultra-precision machining technologies for micro injection mould making; and the surface treatment of mould tools in micro injection moulding.

Part three looks at 'Micro Molding Key-Enabling Technologies' - vacuum-assisted micro injection moulding; modelling and simulation of micro injection moulding; metrological quality assurance in micro injection moulding; Additive Manufacturing for micro-tooling and micro-part rapid prototyping. Part four covers 'Multimaterial Micro Processing' - micro Powder Injection Moulding and multi-material micro injection.

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## CoreTech System launches Moldex3D R17

CoreTech System Co., Ltd. (Moldex3D), Taiwan, has released Moldex3D R17, its injection moulding simulation solution. According to the company, Moldex3D R17 will allow users to consider the dynamic response of an injection moulding machine to ensure that the optimised processing conditions obtained from the analysis can be directly applied on the shop floor, bridging the gap between simulation and manufacturing.

Additionally the barrel compression functionality provides a realistic prediction of material behaviours by simulating the actual compression behaviour of melts inside the barrel and the nozzle, which allows engineers to take into account the effect of material compressibility when injecting into the cavity - generating a more accurate injection pressure prediction.

Venny Yang, President of CoreTech System, stated, "The release of R17 marks a major milestone for Moldex3D. The more powerful physical-virtual integration capability and more timely design insights will largely benefit designers, tool makers and CAE engineers to help them further advance smart manufacturing capabilities and ultimately enhance their global competitiveness."

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## Cummins becomes one of the first customers to invest in GE's Binder Jet technology

Cummins Inc., Columbus, Indiana, USA, is set to expand its Additive Manufacturing capabilities by implementing GE Additive's new, high-precision Binder Jetting AM technology. Cummins, a global corporation of business units which design, manufacture, distribute and service a broad portfolio of power solutions, is one of the first customers to invest in GE's Binder Jet technology, which is called the H2 and is in its beta-stage.

According to the company, this investment will support its plan to develop its manufacturing processes, and it will initially focus on additively manufacturing low-volume parts as it investigates the best way to use AM technology in higher-volume manufacturing.

"By investing in 3D metal additive technologies from GE Additive, we are investing in Cummins and our customers," stated Tim Millwood, Vice President of Global Manufacturing at Cummins Inc. "This technology has the potential to provide our customers with a quicker, lower-cost production method that ultimately uses less energy, which means we can better serve our customers and reduce our environmental impact."

Cummins recently sold its first metal additively manufactured part, produced on a GE Additive Concept Laser M2 system. The company currently has two Concept Laser M2 machines; one is installed at the Cummins Technical Center in Columbus, Indiana, USA, and the other, along with two further machines, is installed at the Cummins Research and Development Center in San Luis Potosi, Mexico.

Cummins is a strategic partner for GE Additive, which revealed the first prototype of its Binder Jet system, then called the H1, in December 2017. The company is



GE's Binder Jet system, the H2, is in its beta-stage (Courtesy GE Additive)

now quickly scaling its Binder Jet technology, first into pilot lines, then into a complete, industrialised factory solution – expected to be commercially available in early 2021. With the addition of GE's Binder Jet technology, Cummins expects to be able to additively manufacture medium to large sized complex parts at high throughput and at a comparatively lower cost.

"In early 2019, we launched the beta testing and partner programme and deliberately sought out partners and key customers, like Cummins, who are committed to mass production," stated Jake Brunsberg, Binder Jet Product Line Leader at GE Additive. "As Cummins celebrates its 100th year, it remains steadfast in its commitment to being at the cutting edge of innovation. Above all, we want to partner with companies whose businesses and customers will benefit tremendously from Binder Jet technologies."

Cummins' Binder Jet systems are reportedly located at GE Additive's laboratory in Cincinnati, Ohio, USA. It's expected that teams from Cummins will be co-located at the lab to work on technology development before the Binder Jet system is relocated to one of the company's facilities later this year.

[www.cummins.com](http://www.cummins.com)

[www.ge.com/additive](http://www.ge.com/additive) ■

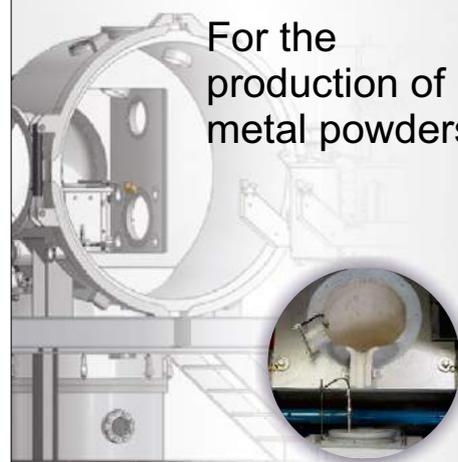


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## High-temperature MIM418 superalloys produced using the master alloy approach

Cast K418 nickel-base superalloys are commonly used to produce automotive turbocharger wheels because of their excellent high-temperature mechanical properties, good fatigue strength and good oxidation and corrosion resistance. Researchers at the Institute for Advanced Materials and Technology at the University of Science and Technology Beijing, the School of Materials Science and Engineering at Xiangtan University and SAIC Volkswagen, Shanghai, China, have previously conducted work on the possibility of using the Metal Injection Moulding of gas atomised pre-alloyed K418 (designated MIM418) powder as an alternative to cast K418. They found that, whilst the

gas atomised powder has the fine particle size, low O<sub>2</sub> content and good flowability suitable for MIM, the high cost of this type of powder greatly limits its applications such as superalloy turbocharger components.

In a paper by Xiaowei Chen, *et al*, published in the *Journal of Alloys and Compounds*, Vol. 771, 2019, pp 33-41, the authors reported on a more cost-effective alternative to fully pre-alloyed gas MIM418 superalloy atomised powder. They used instead a gas atomised master alloy (MA) superalloy powder (designated MA35Ni), which was mixed with elemental carbonyl nickel powder in a ratio of MA35Ni:Ni = 65:35. The chemical composition of the MA powder and the target MIM418 superalloy composition are shown in Table 1.

The MA35Ni powder was stated to have low oxygen content (490 ppm) with average particle size 24.4 µm and this was mixed with carbonyl nickel powder having particle size of -5 µm for 2 h. The blended

	Ni	Cr	Al	Ti	Mo	Nb	Zr	C	B
Pre-alloy powder	Bal.	12.5	5.95	0.75	4.3	2.15	0.105	0.12	0.014
MA35Ni master alloy powder	Bal.	19.23	9.15	1.15	6.6	3.3	0.16	0.18	0.022

Table 1 Chemical compositions of pre-alloyed powder and MA35Ni master alloy powder for MIM418 (wt. %). (Published in the paper 'Phase evolution and densification behaviour of MIM418 superalloy utilizing master alloy approach' by Xiaowei Chen, Lin Zhang, Ye Liu, Xiaoyong Gao, Dan Li and Huifeng Lu in the *Journal of Alloys and Compounds*, Vol. 771, 2019, pp 33-41)

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powders were subsequently blended with a proprietary polyformaldehyde-based binder at 185°C for 2 h, with 60 vol.% powder loading in the feedstock. Prior to sintering, the binder was removed from the injection moulded specimens by catalytic debinding followed by sintering in vacuum at 1000 - 1300°C for different times.

The researchers reported that, whereas the whole of the sintering process for the prealloyed MIM418 superalloy powder formerly studied was done in the solid phase with no phase transformations, the MA35Ni powder is a multiphase, multicomponent master alloy that contains high concentrations of solute elements and several non-equilibrium phases, including MC' carbides,  $\gamma'$  phase and NiAl intermetallic compound. Therefore, the sintering of the MA: Ni carbonyl powder mixture involves much more complex diffusion processes. Also, since diffusion plays an important role in high-temperature thermally activated processes such as homogenisation, carbide precipitation and  $\gamma'$  evolution, the authors stated it was essential to understand how the alloying elements diffuse in the alloys and the phase evolution process, in order to better design the master alloy composition, perform solution heat treatment and understand mechanical properties. The aim of the present work was, therefore, to investigate the phase transition and diffusion process during sintering and the relationship between phase transition, diffusion process and the densification behaviour of the alloy during sintering.

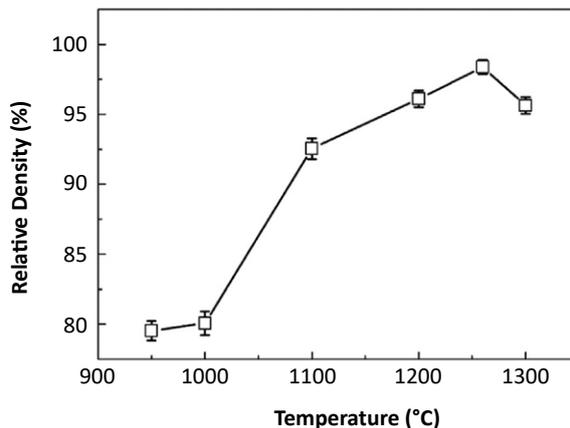


Fig. 1 Relative density of MIM418 using MA35Ni master alloy powder sintered at various temperatures for 2 h. (Published in the paper 'Phase evolution and densification behaviour of MIM418 superalloy utilizing master alloy approach' by Xiaowei Chen, Lin Zhang, Ye Liu, Xiaoyong Gao, Dan Li and Huifeng Lu in the Journal of Alloys and Compounds, Vol. 771, 2019, pp 33-41)

Fig. 1 shows the relative density of MIM418 samples using MA35Ni master alloy powder sintered in vacuum up to 1300°C for 2 h. Accelerated densification of the samples was observed in the temperature range of 1000-1100°C due to the transient liquid phase. However, the authors

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attributed densification not only to the presence of a transient liquid phase, but also to the faster diffusion and particle dissolution and the easier rearrangement of solid phase in the presence of liquid phase. At 1100-1260°C, the transient liquid phase disappears and densification slows down. The highest density achieved using the master alloy approach is 98.4% at 1260°C. Any further increase in the sintering temperature above 1300°C was found to induce deformation and partial melting of the MIM specimens, leading to the decrease in relative density.

The researchers concluded that they had succeeded in producing MIM418 superalloys with excellent mechanical properties using the master alloy approach. At 700-900°C, the  $\gamma'$  phase forms largely with the fast diffusion of Al from master alloy to  $\gamma$  matrix. The transient liquid phase occurs at 1057°C and accelerates the diffusion of dissolving elements and the densification between master alloy powder and Ni powder. At 1260°C, the densification and homogenisation are almost complete. The MC carbides in the master alloy powder change to M<sub>23</sub>C<sub>6</sub> carbides at 900-1100°C and finally to thermodynamically stable MC carbides in the homogenised sample. At the sintered density of 98.4%, the ultimate tensile strength of MIM418 superalloy produced using the master alloy approach is up to 1047 MPa, which

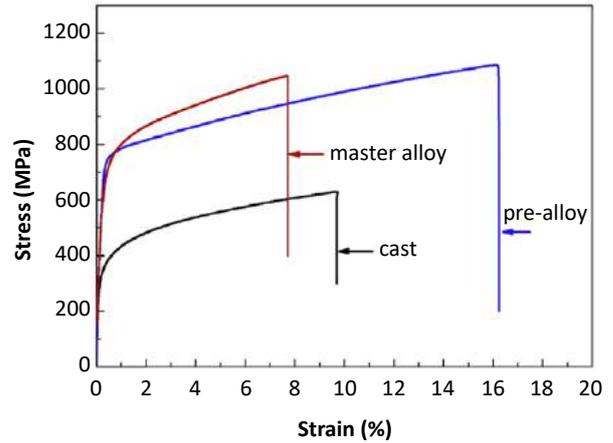


Fig. 2 Stress-strain curves of the MIM418 superalloy prepared by various methods. (Published in the paper 'Phase evolution and densification behaviour of MIM418 superalloy utilizing master alloy approach' by Xiaowei Chen, Lin Zhang, Ye Liu, Xiaoyong Gao, Dan Li and Huifeng Lu in the Journal of Alloys and Compounds, Vol. 771, 2019, pp 33-41)

is similar to the strength of the prealloyed MIM418 superalloy sample, but is much higher than that of the cast K418. Stress-strain curves and mechanical properties for the three approaches to producing 418 superalloy are shown in Fig. 2 and Table 2.

It was concluded that MIM418 superalloys prepared using the master alloy method show great potential for turbocharger and other high-temperature applications by a combination of good mechanical properties and obvious cost advantages.

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Process method	Ultimate strength (MPa)	Yielding strength (MPa)	Elongation (%)
Casting	629	349	8
Pre-alloyed	1085	746	12
Master alloy	1047	746	8

Table 2 Comparison of mechanical properties of MIM418 components prepared by various methods. (Published in the paper 'Phase evolution and densification behaviour of MIM418 superalloy utilizing master alloy approach' by Xiaowei Chen, Lin Zhang, Ye Liu, Xiaoyong Gao, Dan Li and Huifeng Lu in the Journal of Alloys and Compounds, Vol. 771, 2019, pp 33-41)



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## MIM nickel-based Metal Matrix Composites show good wear properties

Metal Matrix Composites (MMCs), composed of carbide particles reinforcing a metal matrix, are widely used in industrial and aerospace applications because of the combination of high hardness, for good wear resistance in abrasive environments, and good toughness properties at room and elevated temperatures. However, little research has been done on the processing of MMC components by Metal Injection Moulding. Researchers at the National Institute of Technology, Karnataka, Mangalore, and CSIR-Central Mechanical Engineering Research Institute in Durgapur, India, have been studying the use of MIM to produce defect-free nickel-based MMCs (NMMC). They have evaluated both the optimum MIM conditions and the adhesive wear behaviour of

the sintered MIM NMMC at room and elevated temperatures under varying loads. The results of the research to produce MIM NMMC components have been published in the journal *Silicon* (Vol. 11, 2019, 175-185) by authors V N Chinnathayppal, R M Rangarasalah, V Desai, and S K Samanta.

The authors used a fine Ni-based self-fluxing alloy NiCrSiB (70 wt.%) powder, which was mechanically mixed with Cr<sub>3</sub>C<sub>2</sub>-NiCr (30 wt.%) using high-energy ball milling. The chemical composition is shown in Table 1. Particle size distribution ranged from fine 8.65 µm at D10 to 28.11 µm at D97. Fig. 1 shows the morphology of the NMMC powder at the mixed wt.% ratio mentioned above. The NMMC powder with volume fraction of 56% was mixed with binder comprising polyethylene glycol (10 wt.% PEG), low density

Alloy	Cr	Ni	C	Fe	B	Si	Cu	Others
NiCrSiB	15.7	72.16	0.45	2.72	3.92	4.11	1.94	-
Cr <sub>3</sub> C <sub>2</sub>	86.16	-	13.3	0.3	-	-	-	0.24
NiCr	20.4	78	-	0.2	-	-	-	1.05

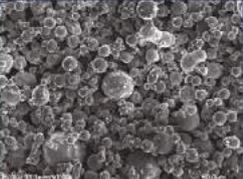
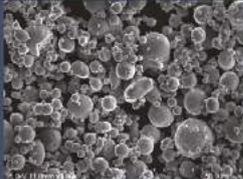
Table 1 Chemical composition of NiCrSiB (70 wt.%) + Cr<sub>3</sub>C<sub>2</sub>-NiCr (30 wt.%) NMMC powder. (From the paper 'Evaluation of Wear Behaviour of Metal Injection Moulded Nickel-based Metal Matrix Composite', published in *Silicon*, Vol.11, 2019, pp 175-185)



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polyethylene (35 wt.% LDPE), paraffin wax (52 wt.% PW) and stearic acid (3 wt.% SA) to produce the MIM feedstock.

The resulting NMMC feedstock was characterised using Differential Scanning Calorimetry (DSC) and a Thermal Gravimetric Analyser (TGA). Rheological behaviour of the feedstock was determined using a rotational viscometer. Shear rates were examined in the range from 10 to 2500 S<sup>-1</sup> and at temperatures from 170 to 180°C in steps of 5°C. A standard injection mould with ejection system was used to produce tensile test specimens in a 150 ton injection moulding machine. The DSC result showed that the injection temperature of the feedstock should be above 176°C and mould temperature should be below 43°C for successful injection moulding.

The injection moulded green compacts were subjected to solvent debinding in hexane at 48°C and

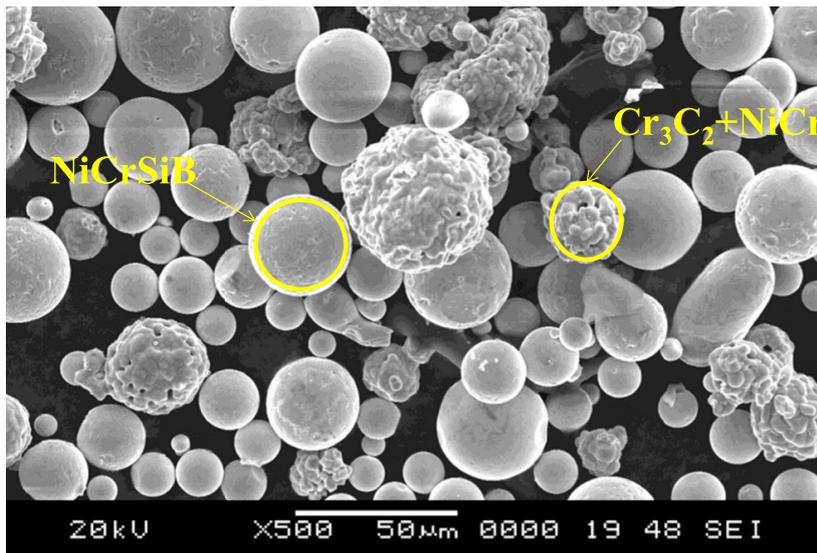
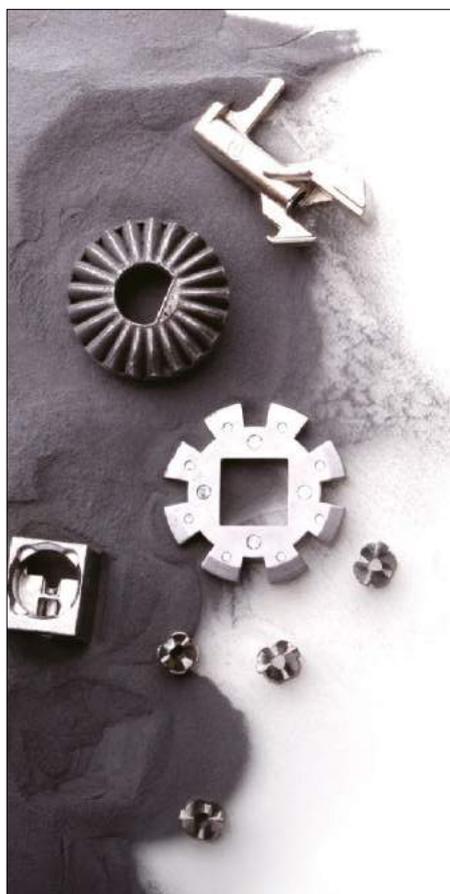


Fig. 1 Morphology of NiCrSiB (70 wt.%) + Cr3C2-NiCr (30 wt.%) NMMC powder blend. (From the paper 'Evaluation of Wear Behaviour of Metal Injection Moulded Nickel-based Metal Matrix Composite', published in Silicon, Vol.11, 2019, pp 175-185)

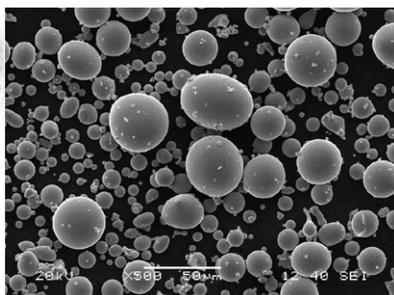
thermal debinding for 5 h at 500°C to remove the backbone binder LDPE and the rest of the PW, PEG-600 and SA, which remained

after solvent debinding. This was followed by sintering at a temperature of 1250-1300°C (heating rate at 10°C/in) under hydrogen purged



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Material	Length (Shrinkage %)	Width (Shrinkage %)	Thickness (Shrinkage %)	Density (kg/m <sup>3</sup> )	Microhardness (Hv)	Ultimate tensile strength (MPa)
NMMC	14.98 - 15.63	16.22 - 17.56	15.43 - 16.73	4149	710	321

Table 2 Linear shrinkage, density and mechanical properties of MIM NMMC. (From the paper 'Evaluation of Wear Behaviour of Metal Injection Moulded Nickel-based Metal Matrix Composite', published in *Silicon*, Vol.11, 2019, pp 175-185)

atmosphere to prevent oxidation. Fig. 2 shows SEM images of the NMMC at different stages of MIM processing.

Table 2 shows properties of the MIM NMMC including shrinkage, density, microhardness and tensile strength. Vickers microhardness measurements were conducted on the cross-sectional area of the tensile bar, at the core region. Maximum hardness value – Vickers microhardness of 710 HV - is observed in test samples sintered at a temperature of 1280°C.

Wear test analyses on the sintered NMMC were performed under dry sliding conditions using pin-on-disc apparatus as per standards, at constant sliding distance of 3000 m and velocity 1 m/s under room temperature and elevated temperature of 200°C and 400°C.

The load and temperature have a significant influence on the wear loss of the material. Three tests were performed for each temperature and load and an average friction coefficient was thus calculated within the steady-state system. The wear rate

due to adhesion is highest for the MIM NMMC at a temperature of 400°C for 40 N load and lowest at room temperature for 10 N load. Wear rate scars were found to increase gradually with an increase in the tempering temperature. Wear mechanisms were also analysed using Scanning Electron Microscopy (SEM). Contact: veru29@gmail.com

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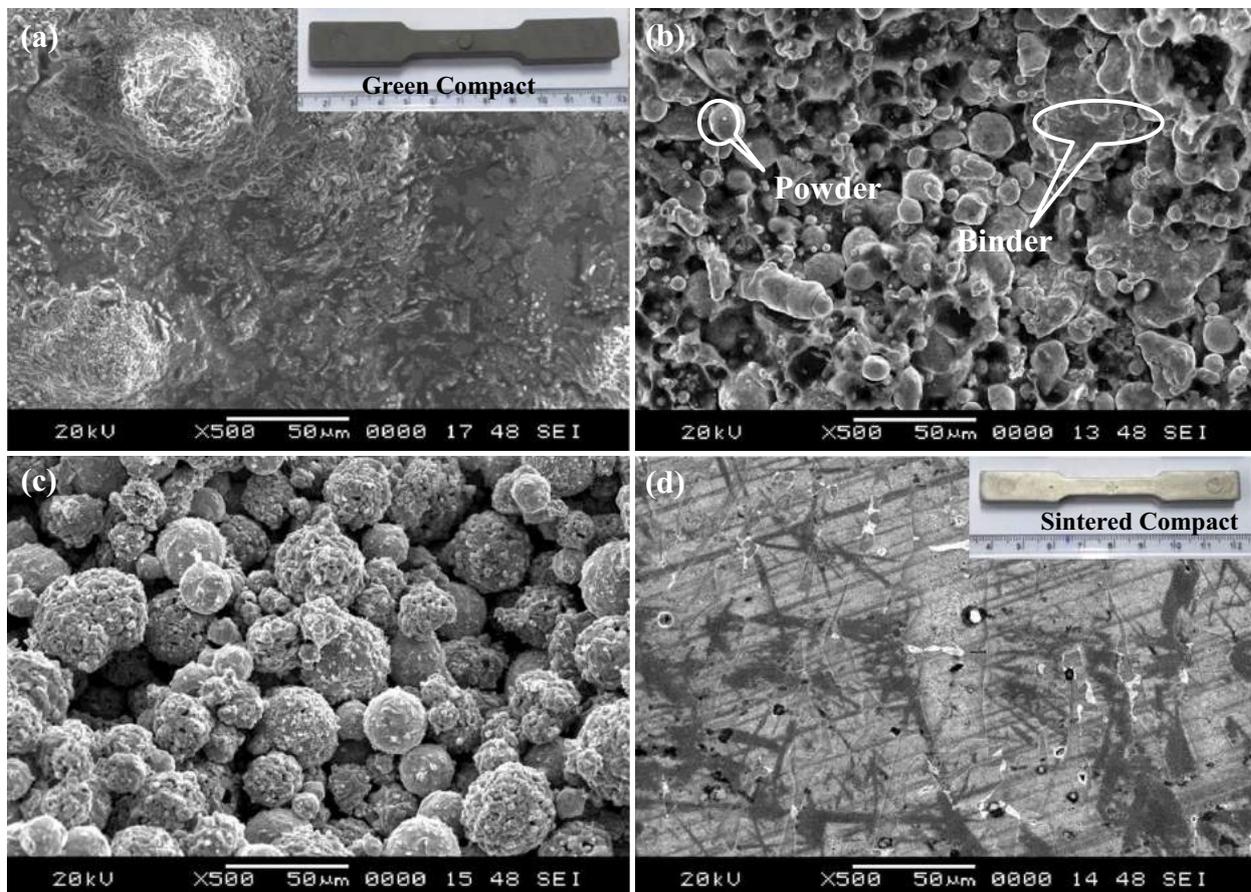


Fig.2 SEM of (a) Green compact before debinding (b) Green compact after solvent debinding at 48°C for 5 hours (c) Green compact after thermal debinding (d) Sintered compact at 1280°C (From paper: 'Evaluation of Wear Behaviour of Metal Injection Moulded Nickel-based Metal Matrix Composite', published in *Silicon*, Vol.11, 2019, pp 175-185).



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### Binder system design

#### Characteristics required for Binder

- **High flowability at molding temperature**  
Binder design considering the viscosity at around the molding temperature.
- **High expansion property in the mold during injection moulding**  
Wide moulding condition range because of the Barus Effect. (Fig.1 and 2)
- **High thermal decomposition property in the de-binding process**  
There is no effect on the sinter quality, because there is no residue after de-binding. (Fig.3)

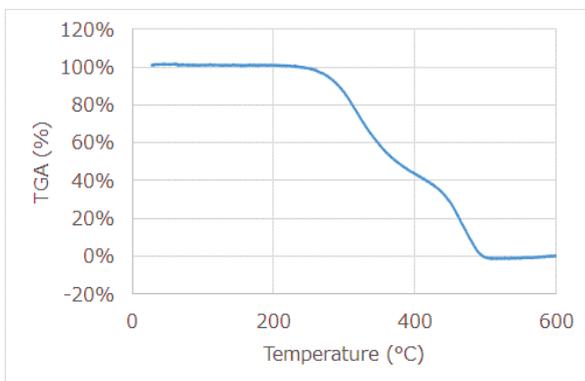


Fig.3 TGA Curve of Binder

※All components are vaporized at around 500°C.

The flow amount  $F$ , when the load  $S$  is applied to the thermoplastic fluid, is given as following equation.

$$F = aS^n$$

Here,  $a$  is the flow characteristic at load=1,  $n$  is Barus effect.

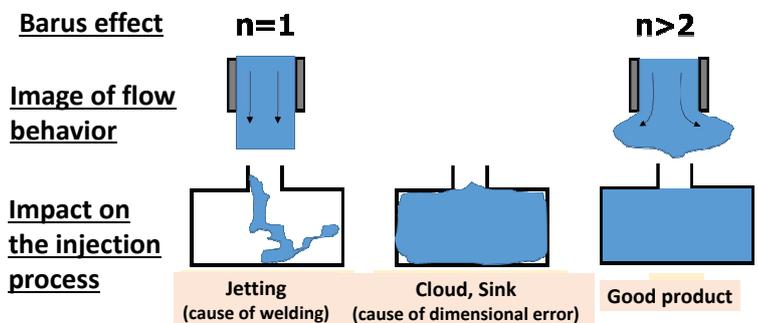


Fig.1 Schematic of the relationship between  $n$  value and flow characteristic

※Since larger  $n$  value, material expands in the mould, dense green part is obtained.

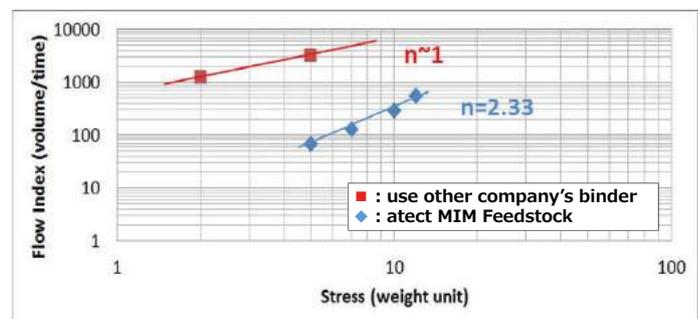


Fig.2 Flow characteristic compared with pellets using the other company's binder

※With our binder, it is possible to obtain precise green part because material easily expands in the mould.

# Influence of powder loading on density and microstructure of MIM Fe-50Ni soft magnetic alloys

Fe-50Ni soft magnetic alloys are commonly used for electromagnetic applications such as printers, relays, disk drives, hearing aid devices and fuel injection components in vehicles, to name just a few. Many of these applications now require the soft magnetic parts to be micro-sized and of complex shape, which means that conventional processing by machining of wrought Fe-Ni alloys is not very cost-effective. Even the press and sinter route is often not suitable, because the high level of porosity in the sintered parts can result in lower magnetic properties.

Research being carried out by M Ali, *et al*, at the Universiti Teknologi Petronas, Seri Iskandar, Malaysia, in cooperation with researchers at Center of Excellence in Science and Applied Technologies, Islamabad, and COMSATS, Sahiwal, Pakistan, has focused on developing the Metal Injection Moulding process as a cost-effective alternative to producing micro, complex-shaped components with high dimensional accuracy from Fe-50Ni soft magnetic alloys. The researchers claim that the higher density and improved microstructure achieved in Fe-50Ni parts produced using MIM will lead to enhanced magnetic performance. The results of their research to date have been published in the journal *Materials Science & Engineering Technology*

(Vol. 50, March 2019, pp 274-282).

The authors stated that powder loading is a crucial parameter in the MIM process, which controls the densification and microstructure of the sintered parts. A lower powder loading could lead to various defects and lower densification, whereas higher loading can result in failure of parts during injection moulding. Therefore, it is important to engineer an appropriate level of powder loading in order to achieve defect-free parts, along with higher densification and improved microstructure.

The authors used a fine carbonyl iron powder, which is spherical in shape, and a fine carbonyl nickel powder, which has a spiky three-dimensional filament structure. Specifications for the two powders are shown in Table 1. The iron and nickel powders were uniformly mixed at a ratio of 1:1 and then blended in a turbular mixer to achieve a

homogeneous distribution of the powders throughout the matrix. The Fe-Ni powder blend was then mixed with a binder comprising 75% paraffin wax, 5% stearic acid and 20% polypropylene using a Z-blade mixer to produce the MIM feedstocks. In the current research, three feedstocks were compounded with the powder loading by volume of 57% (F1), 54% (F2) and 52% (F3). The binder composition was similar for all the formulations.

Dog bone green test pieces (according to *MPIF Standard 50*) were injection moulded using a low pressure injection moulding machine. The green parts were moulded at  $175 \pm 5^\circ\text{C}$  temperature and 4.5 bar pressure with moulding times varying from 10 seconds to 25 seconds. The mould temperature was kept at  $45 \pm 5^\circ\text{C}$ . Various defects were observed during the injection moulding of feedstock F1 due to the higher powder loading (57 vol.%), whereas feedstocks F2 (54 vol.% loading) and F3 (52 vol.% loading) were successfully moulded without physical defects (Fig. 1a). The feedstocks were analysed by

Powder	Particle size ( $\mu\text{m}$ )	Impurity (wt.%)			SSA ( $\text{m}^2/\text{g}$ )	BD ( $\text{g}/\text{cc}$ )
		C	O	N		
Carbonyl iron	4.643	0.45	0.30	0.02	1.29	2.63
Carbonyl nickel	6.391	0.28	0.20	0.01	0.939	2.70

Table 1 Specifications of iron and nickel powders (SSA: Specific surface area, BD: Bulk density). (From the paper 'Influence of powder loading on densification and microstructure of injection moulded Fe-50Ni soft magnetic alloys', by M Ali, *et al*, *Materials Science & Engineering Technology* Vol. 50, 2019, pp 274-282)

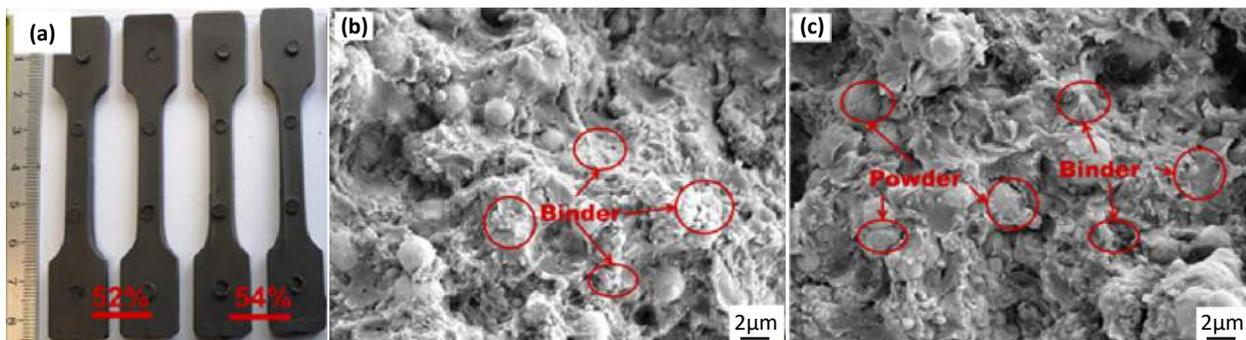


Fig. 1 Image of (a) Injection moulded defect-free parts, field emission SEM images of feedstock with formulation (b) F2 and (c) F3. (From the paper 'Influence of powder loading on densification and microstructure of injection moulded Fe-50Ni soft magnetic alloys', by M Ali, *et al*, *Materials Science & Engineering Technology* Vol. 50, 2019, pp 274-282)

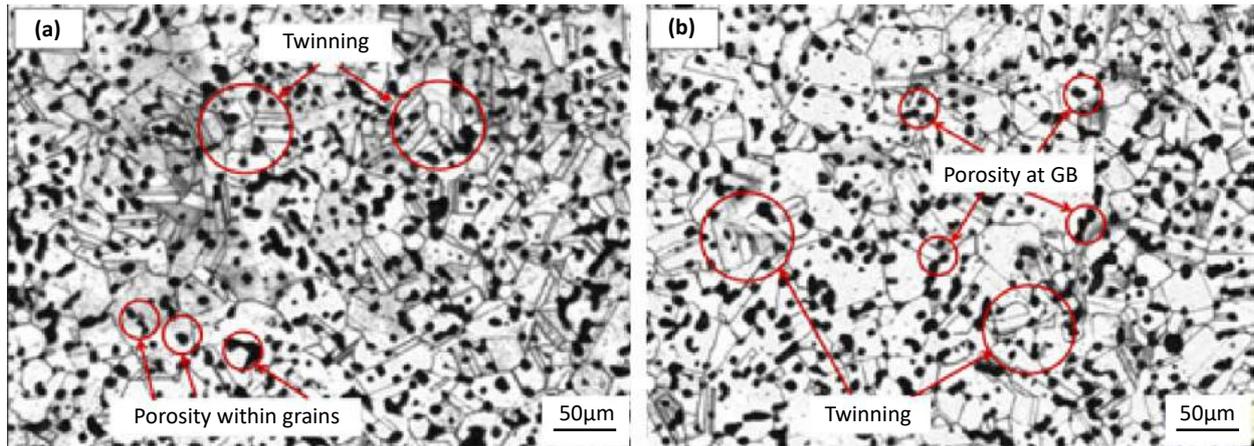


Fig. 2 Micrographs of sintered MIM Fe-50Ni samples with powder loading (a) 52% and (b) 54%. (From the paper 'Influence of powder loading on densification and microstructure of injection moulded Fe-50Ni soft magnetic alloys', by M Ali, et al, *Materials Science & Engineering Technology* Vol. 50, 2019, pp 274-282)

field emission Scanning Electron Microscopy for homogeneity of the binder and powders. The feedstock was found to be homogeneous due to voids between the metal particles being filled by the binder as seen in Fig. 1b, c.

The polymeric binder was removed in two phases, namely solvent and thermal debinding. The solvent extraction was done by immersing green samples in n-heptane (C<sub>7</sub>H<sub>16</sub>) solution at 60°C in a circulating water bath with immersion time of 10 h. The thermal debinding cycle was designed according to the binder degradation temperature range determined by thermogravimetric analysis. After thermal debinding, the test samples were sintered in 5% hydrogen; balance argon at 1325°C for 120

minutes with a heating rate of 2°C/min. The integrated thermal debinding and sintering cycle, including dwell times at different temperatures, took 20 h followed by cooling of the MIM Fe-50Ni parts to room temperature.

It was established that densification can be enhanced by increasing powder loading without using sintering aids and high-pressure sintering. For feedstock F2 with 54% powder loading, 90.70% of the theoretical density was achieved whilst increasing loading to 52% in F3 allowed sintered density to reach 91.6%. It was also established that microstructures of both formulations F2 and F3 indicate the formation of the austenite phase after sintering at 1325°C. Iron and nickel peaks disappeared and only

peaks of  $\gamma$ -FeNi phase were detected, which indicates complete alloy formation. Fig. 2 shows the sintered microstructure of F2 and F3 MIM Fe-50Ni alloys.

Vickers hardness of sintered specimens was also measured and it was observed that hardness increased from 107 HV0.5 to 111 HV0.5 with increase in loading from 52% to 54% respectively.

It was concluded that optimal powder loading of 54% is the best from the perspective of enhanced densification and improved microstructure to assure the quality parts of soft magnetic Fe-50Ni alloys using Metal Injection Moulding. Contact: faizahmad@utp.edu.my

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# The effect of sintering conditions on the magnetic behaviour of nickel-free MIM X15 CrMnMoN 17-11-3

At the MIM2019 International Conference on Injection Moulding of Metals, Ceramics and Carbides, Orlando, Florida, USA, February 25-27, a presentation from Dr Shin Lee, Dr Chung-Huei Chueh and I-Shiuan Chen, Chenming Mold Ind. Corp. (UNEEC), Taiwan, considered the effects of sintering parameters on the magnetic properties of X15 CrMnMoN 17-11-3 austenitic stainless steels processed via Metal Injection Moulding.

Recent technology trends and demands from the communication and electronics industry are increasing, in terms, for example, of high strength, non-magnetism, high corrosion resistance and good surface quality. In this study, high-nitrogen and nickel-free X15 CrMnMoN 17-11-3 austenitic stainless steel, one of the promising candidates, was fabricated by the MIM process using commercial polyoxymethylene-based feedstocks.

All of the main MIM process steps were carried out for this study, from mould design and injection moulding to debinding and sintering. The green parts were first debound in fuming nitric acid, followed by secondary thermal debinding and then sintering based on several designed profiles, as shown in Fig. 1. All profiles were run in a 60 kPa N<sub>2</sub> atmosphere.

Table 1 lists the relative magnetic permeability and nitrogen content of sintered parts obtained from profiles 1 to 4. It is evident that lower magnetic permeability and higher nitrogen content could be obtained via profile 3. Based on the definition of SEW 390 (Stahl Eisen Werkstoffblatt), the stainless steel could be classified as non-magnetic (paramagnetic) once its relative magnetic permeability is lower than 1.01 and austenitic stainless steels should be paramagnetic due to the FCC crystal structure.

In this regard, profile 3 is the optimal one among those studied. As for the abnormal ferromagnetism with

higher relative magnetic permeability, UNEEC next examined the crystal structure, since it is rational to suspect this ferromagnetism phenomenon is highly correlated with

the presence of a non-FCC phase in the sintered parts.

Fig. 2 shows that, in the XRD patterns for profiles 1 to 4, BCC peaks were not found; instead, FCC peaks dominated. This might be due to the ferromagnetic phase's volume fraction being too small to be detected using XRD equipment; hence, UNEEC next investigated the sintered parts

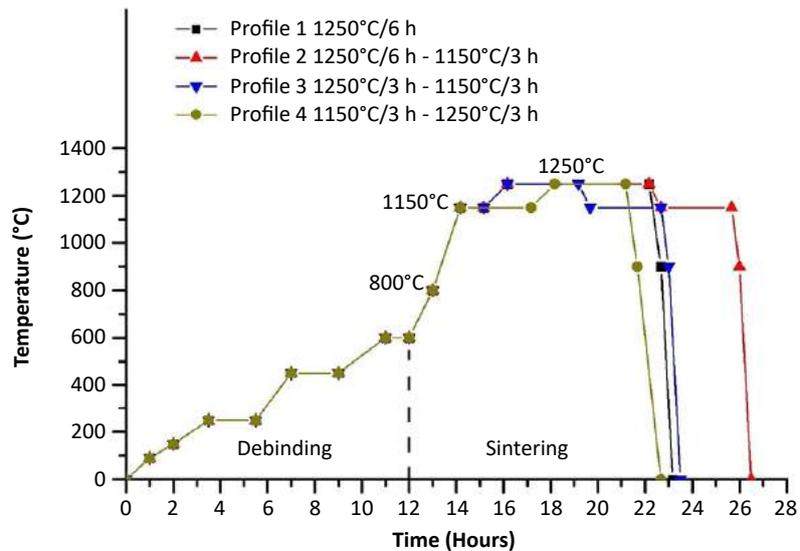


Fig. 1 Sintering profiles for X15 CrMnMoN 17-11-3

	Profile 1	Profile 2	Profile 3	Profile 4
Average Relative Magnetic Permeability ( $\mu_{rel}$ )	1.056	1.012	1.008	1.027
Average Nitrogen content (wt.%)	0.56	0.68	0.70	0.59

Table 1 Relative magnetic permeability and nitrogen content for sintering profile 1 to 4

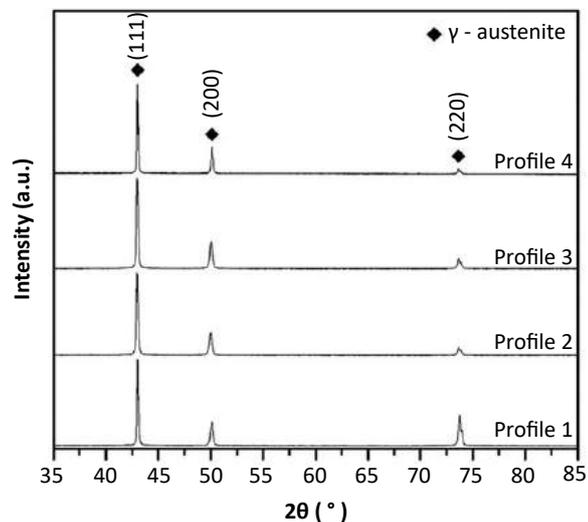


Fig. 2 XRD for X15 CrMnMoN 17-11-3 sintered parts from profiles 1 to 4

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via Electron Backscatter Diffraction (EBSD) and Electron Probe Micro-Analyser (EPMA) analysis, as shown in Fig. 3. Comparing Fig. 3(a) to 3(d), we can clearly see that the ferromagnetism of profiles 1, 2 and 4 is due to the presence of  $\delta$ -ferrite near the surface region and this BCC phase is the root cause for the abnormal ferromagnetism. Comparing Fig. 3(e) to

3(h) for EPMA Mn elemental mapping, it is evident that intensive sublimation and evaporation of Mn is also revealed in profiles 1, 2 and 4. In addition to nitrogen, Mn is also the stabilisation element for austenitic stainless steels and this implies that the loss of Mn will cause the FCC austenite phase to be destabilised and thus transformed to BCC  $\delta$ -ferrite phase.

For these reasons, UNEEC suggested that this is the root cause of the abnormal ferromagnetism phenomenon for X15 CrMnMoN 17-11-3 austenitic stainless steels.

Contact: Dr Shin Lee, Dr Chung-Huei Chueh, and I-Shiuan Chen, email: tim\_lee@tw.uneec.com www.uneec.com ■

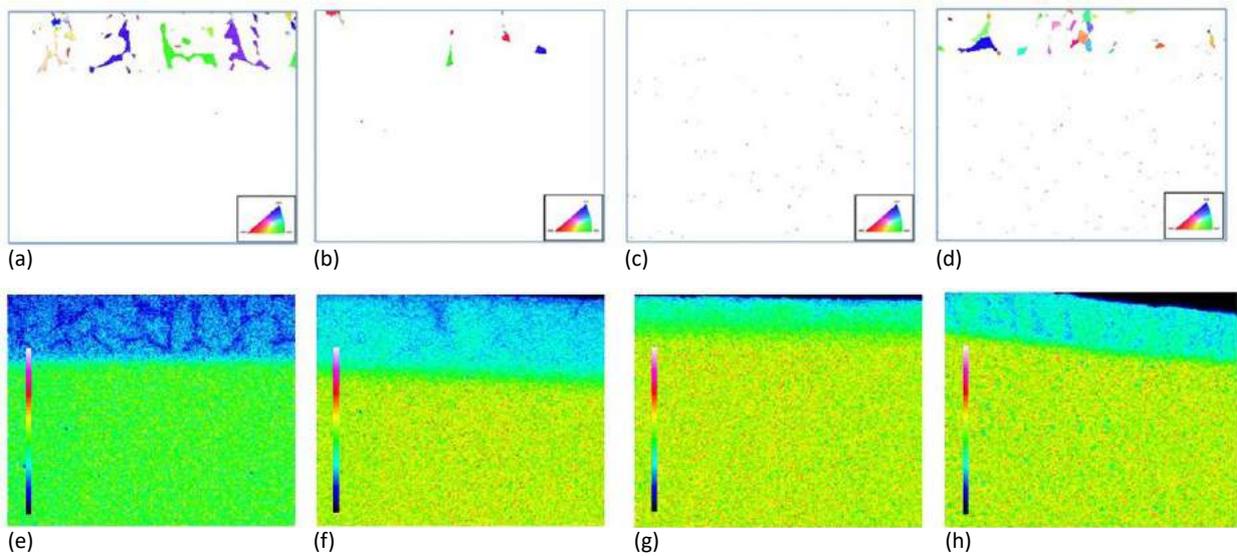
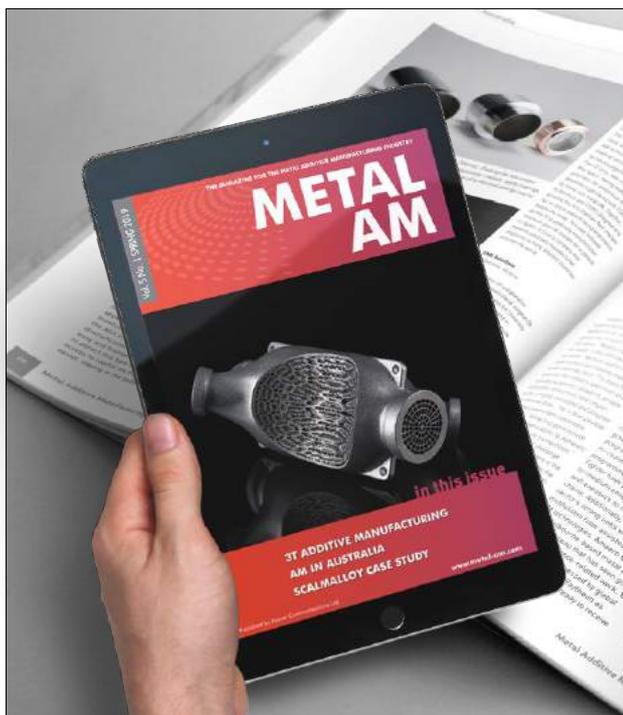


Fig. 3 EBSD and EPMA mapping for X15 CrMnMoN 17-11-3 sintered parts based on profiles 1 to 4. [a] [b] [c] [d] EBSD of BCC phase mapping for profiles 1 to 4 respectively, [e] [f] [g] [h] EPMA of Mn elemental mapping for profiles 1 to 4 respectively





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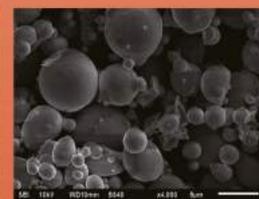
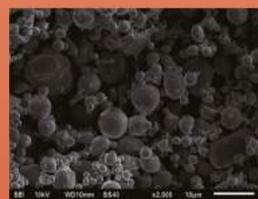
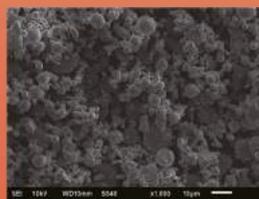
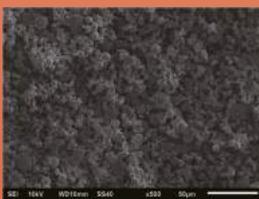
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17-4PH	4.7	0.34	7.7
304L	4.8	0.34	7.8
HK30	4.7	0.34	7.7
4J29	4.9	0.34	7.95
F75	5.0	0.34	8.1



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# Low-Pressure Powder Injection Moulding: Enabling cost-effective low and high-volume production

The vast majority of metal and ceramic injection moulded parts are today produced on high-pressure injection moulding machines, operating at up to 200 MPa. However, Low-Pressure Powder Injection Moulding (LPIM), using pressures of up to 1 MPa, has been a focus of international development for a number of years. LPIM is now enjoying commercial success, driven partly by its ability to produce components at both low and high volumes, many of which are larger than can be produced by conventional PIM. Prof Vincent Demers outlines the current status of the technology and highlights the key technical differences between LPIM and conventional PIM.

Recent progress in feedstock formulations has generated new opportunities for the injection of low-viscosity feedstocks into a mould cavity using an injection pressure that is up to two hundred times lower than that used in the conventional High-Pressure Powder Injection Moulding (HPIM) process. The Low-Pressure Powder Injection Moulding (LPIM) process consists of the mixing of a ceramic or metallic powder with a low-viscosity binder – one without a backbone polymer – to obtain a feedstock which is injected into a mould cavity, debound, and finally sintered to obtain a near-net shape dense metallic component.

Thanks to this low injection pressure, both the size of the injection machines and the overall size of the moulds are significantly smaller than those required for HPIM. The lower costs associated with smaller tooling offer an opportunity to fabricate intricate parts in a cost-effective way, whether in low or in high production volumes. This article aims to highlight the differences and similarities between LPIM and HPIM.

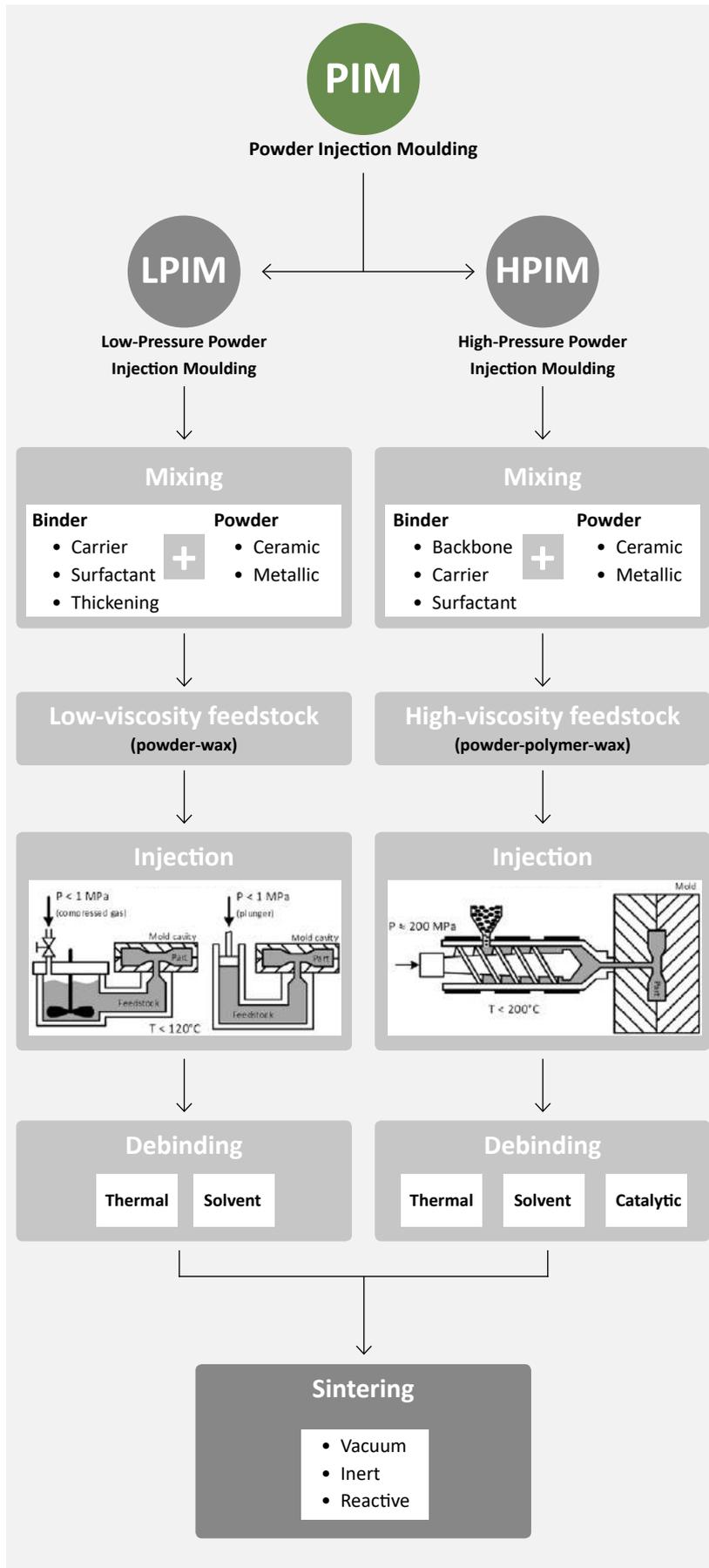
## What is the LPIM process and what are its challenges?

The Powder Injection Moulding process can be divided into two branches according to the viscosity of feedstock, as highlighted in Table 1 and Fig. 1. Although the Low-Pressure Powder Injection Moulding and High-Pressure Powder Injection

Moulding processes are conceptually similar, there are some significant differences between several of the process stages, including mixing, injection and debinding. On the one hand, the LPIM process uses ceramic or metallic powder to form a low-viscosity feedstock that is injected into a mould cavity at low pressure, typically varying from 0.1 to 1 MPa. In contrast, the HPIM process uses a

	LPIM	HPIM
Powder	Metallic & Ceramic	Metallic & Ceramic
Particle size (µm)	1-20	1-20
Binder	Wax / Surfactant / Thickening	Polymer / Wax / Surfactant
Viscosity (Pa·s)	0.1-20	100-1000
Shear during mixing	Low	High
Maximum injection pressure (MPa)	1	200
Maximum injection temperature (°C)	120	200
Clamping force (kN)	5	1000

Table 1 Comparison between LPIM and HPIM



similar ceramic or metallic powder to form a high-viscosity feedstock requiring high pressure varying from 50 to 200 MPa during the injection stage. Whether the injection is performed using LPIM or HPIM principles, the part is then debound and sintered to obtain a dense, near-net shape ceramic or metallic component.

The capability of the LPIM process is characterised by shape complexities similar to that of casting, offering higher complexity than the HPIM process. Mechanical properties are close to forging and similar to HPIM. LPIM offers cost-effectiveness in either low or high production volumes, in contrast to HPIM which is only used for high-volume production.

For over fifty years, the market for PIM-grade powders was dominated by the use of high-viscosity feedstocks using the High-Pressure PIM process. However, during the last ten to fifteen years, low-viscosity feedstocks, formulated with low-molecular weight polymers, have been used in LPIM to increase mouldability and shape complexity. As with HPIM technology, there is no real limitation in terms of the nature of the powder that can be shaped with the LPIM process. Whilst initially developed for forming ceramics, metallic-based feedstocks have been developed for LPIM to manufacture complex parts in the automotive, aerospace and medical industries. Efforts to optimise the mechanical properties of LPIM metallic materials typically involve debinding and sintering using feedstock systems whose optimal mouldability has not yet been demonstrated. Therefore, realising the full potential of the LPIM process is still limited by a poor understanding of the fundamental mechanisms underlying the mouldability and segregation of LPIM feedstocks. Table 2 presents a non-exhaustive list of powders used in LPIM.

Although computer-aided engineering has been used successfully to model the injection stage of

Fig. 1 Comparison between the LPIM and HPIM processes

the HPIM process for metals and ceramics, using ProCAST, ANSYS, Moldflow, or other in-development packages [1–6], the capability of these simulation tools has not been largely demonstrated for the LPIM process. For LPIM feedstocks, the simulation of mould filling, including filling time, filling pressure, mould temperature and flow rate have only been performed for one alumina-based [7–9], one zirconia-based [10], and one stainless steel-based feedstock [11]. It is clear that simulations describing the injection stage using low-viscosity feedstocks have received very little attention in the literature, and this lack of efficient numerical models directly limits the development of LPIM technology. Since simulation provides engineers with numerical feedback and guidelines to anticipate the flow behaviour of the feedstock during the injection process, developing simulation tools adapted to the LPIM process in order to minimise the systematic real-scale injections and full empirical trial and error approach remains a challenge.

**Typical parts produced by LPIM**

Good candidates for the LPIM process are parts with a mass ranging from 0.5–1.5 kg, a length ranging from 5–200 mm, wall thicknesses varying from 0.4–20 mm, and a production volume varying from 150–500,000 parts/year. Tailoring the LPIM process to obtain efficient prototyping and moulding capabilities, as well as low production costs from small-to-large production volumes is feasible. Net shape complex parts, including different gas turbine engine components, orthopaedic implants, orthopaedic disposable/permanent instruments, cardiac instruments, trauma implants and titanium foam products can be manufactured in a wide range of alloys, such as 17-4PH, SS316, CoCrMo, Inconel 625, Ti-6Al-4V and CpTi, using the LPIM process (Fig. 2).

Ceramic powders	Metal powders
<ul style="list-style-type: none"> <li>• Alumina</li> <li>• Zirconia</li> <li>• Silicon nitride</li> <li>• Silicon carbide</li> <li>• Mullite</li> <li>• Spinel</li> <li>• Steatite</li> <li>• Cordierite</li> <li>• Forsterite</li> <li>• Spodumene</li> <li>• Celsian</li> </ul>	<ul style="list-style-type: none"> <li>• 316L stainless steel</li> <li>• 17-4PH stainless steel</li> <li>• Inconel 718</li> <li>• Inconel 625</li> <li>• CoCrMo</li> <li>• Iron</li> <li>• Ti-6Al-4V</li> </ul>

Table 2 Powders used in LPIM



Fig. 2 Example of metallic parts produced by LPIM (top) orthopaedic components: CoCrMo hip stem and stainless steel broaches used as surgical tools (below) Ti64 implant devices for applications in spine and trauma

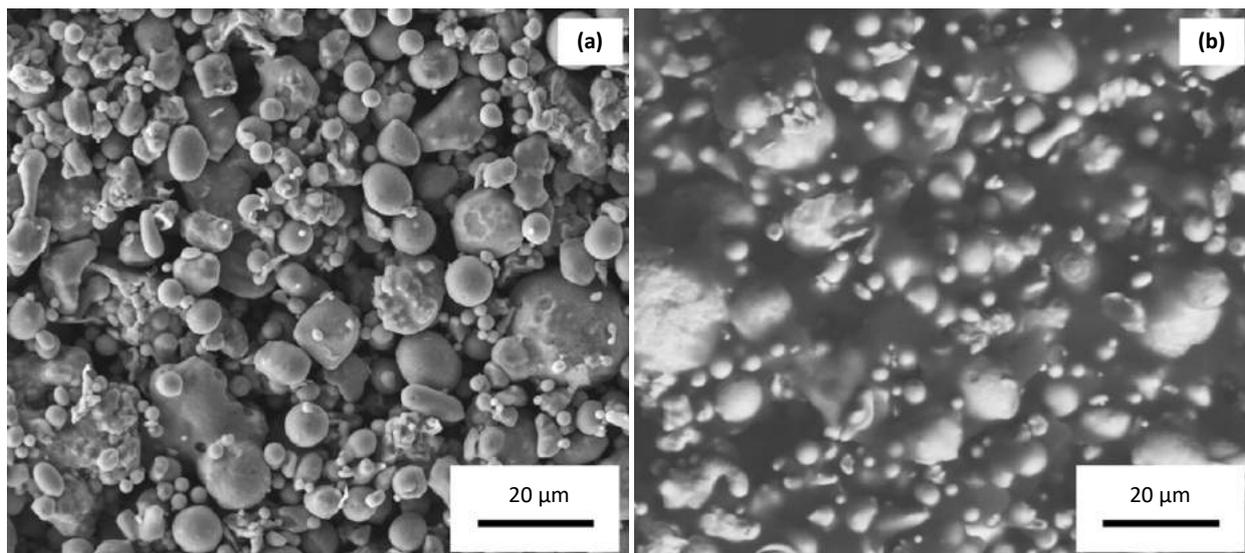


Fig. 3 Typical SEM micrograph of (a) 17-4PH stainless steel dry powder, and (b) wax-based 17-4PH stainless steel feedstock

### Properties of feedstocks used in Low-Pressure Powder Injection Moulding

The characteristics of the powders used in LPIM, such as the solid loading, shape, size and alloy used, are similar to those used in HPIM. The main difference between LPIM and conventional PIM processes is in the binder formulation directly driving the injection and debinding

as is often used in High-Pressure PIM feedstocks to maintain the shape up to the pre-sintering state. The carrier used in LPIM is a single or multi-wax-based binder similar to that used in conventional PIM technology and commonly called the filler phase. This blend of natural and/or synthetic waxes may include paraffin wax, microcrystalline wax, beeswax, carnauba wax, polyethylene waxes, candelilla wax, amongst

interaction, promote the homogeneity of the mixture, and decrease the viscosity of the feedstock. Stearic acid is undoubtedly the most commonly used surfactant agent, but other constituents such as oleic acid, peanut oil, fish oil, castor oil, and zinc stearate are also reported in the literature [16–18].

Since a feedstock containing only waxes and surfactant agents produces a very low viscosity – as low as 0.2 Pa·s – an addition of a thickening agent such as ethylene vinyl acetate or low-density polyethylene is generally required to increase the viscosity of feedstocks and prevent powder-binder separation. As the wax-based carrier and the thickening agent have a certain degree of solubility and similar melting points, all the binder must be extracted together during the debinding cycle (i.e., the thickening agent is not a backbone polymer extracted during secondary stage debinding, as performed in High-Pressure PIM). During the mixing stage, ceramic or metallic powder (Fig. 3(a)) is blended with a molten wax-based binder to produce a homogeneous feedstock in which powder is uniformly distributed within the low-viscosity binder (Fig. 3(b)).

*“ The main difference between LPIM and conventional PIM processes is in the binder formulation directly driving the injection and debinding stages. The LPIM binder formulation is generally composed of three constituents: a carrier, a surfactant, and a thickening agent.”*

stages. The LPIM binder formulation is generally composed of three constituents: a carrier, a surfactant, and a thickening agent. It should be noted that this binder formulation does not contain a backbone polymer,

others, which are used as the main constituents to form commercial and development feedstocks [12–15]. The surfactant agent is a secondary constituent added to the carrier binder to increase the powder-binder

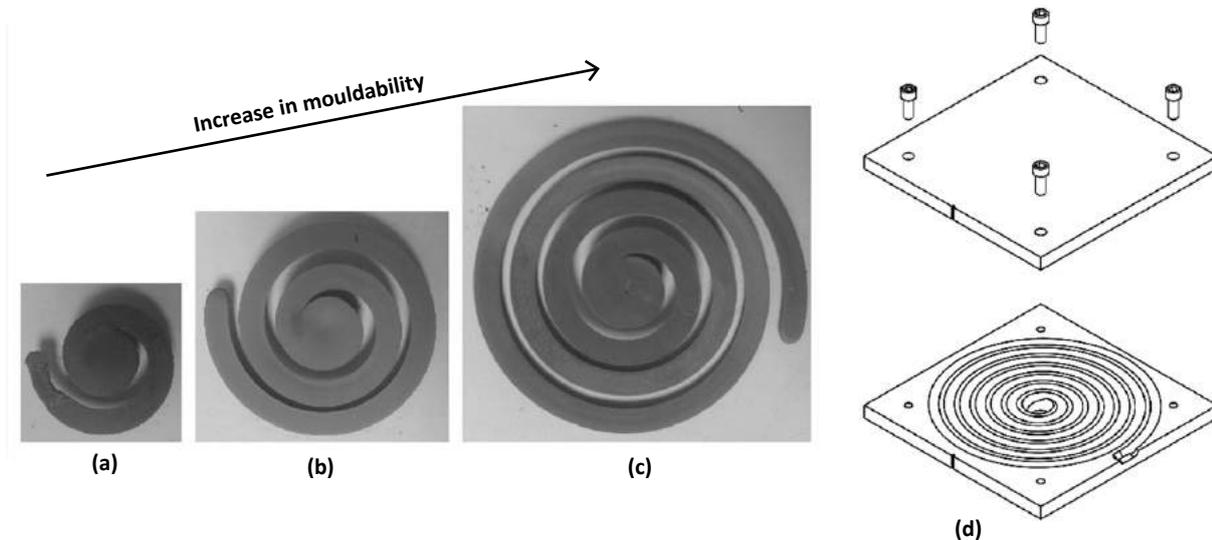


Fig. 4 Quantification of feedstock mouldability using real-scale injection (a-c) injected length results for typical LPIM feedstocks, and (d) spiral mould cavity

### Injection principles arising from low-viscosity feedstocks

The low-viscosity feedstock granulated during the mixing stage is introduced into an injection press, heated up to the melting point of the binder, and injected at low pressure. LPIM machines use either a compressed gas or a plunger to inject the molten feedstock into the mould cavity (Fig. 1). The first injection principle consists of pressurising the feedstock container with compressed gas or air at a typical pressure varying from 0.1 to 1 MPa, to be used as a piston for transporting the feedstock from the container to the mould cavity. Similarly to a syringe, the second injection principle uses an injection cylinder, where the feedstock flows from the container to the piston system, and is then injected into the mould cavity at a pressure varying from 0.1 to 1 MPa, using an electric, pneumatic or hydraulic actuator (or up to 5–7 MPa for Medium-Pressure Powder Injection Moulding Technology [19]). Using either one of these machines, the volumetric flow can be controlled with a proportional valve on a compressed gas line or with the speed of the plunger. Commercial machines available on the market or developed in

laboratories are generally equipped with a mixer system for keeping the feedstock in a homogeneous slurry form between each injection [19–23]. Because of the low pressure required for the LPIM process, the size of the injection machines, as well as the overall size of the moulds, are reduced significantly as compared to the reciprocating screw machines and massive moulds required to accommodate the high pressure experienced in the conventional PIM process.

### Mouldability and segregation properties of LPIM feedstocks

Key to the successful injection of feedstock at low pressure is having suitable rheological properties for the wax-based binder. One of the main challenges in this regard is designing an LPIM feedstock characterised by high mouldability and low segregation. Mouldability is the ability of the powder-binder mixture to adequately fill up the mould cavity, while segregation refers to the inhomogeneous distribution of powder particles in feedstocks. Note that these two parameters are linked to the rheological properties

of the feedstock. Mouldability is often defined as the injected length (as illustrated in Fig. 4(a–c) for three different feedstocks) into a spiral mould cavity (Fig. 4(d)) for given injection parameters [24]. The spiral flow distance is inversely proportional to the viscosity of the feedstock [25]. Similarly to the High-Pressure PIM process, the viscosity of LPIM feedstock is routinely used to predict the mouldability of intricate parts, rather than of using long and expensive real-scale injection tests. It is well accepted that an increase in feedstock temperature, in binder content, in powder sphericity, and in the shear rate applied on the feedstock leads to a decrease in viscosity [26–30].

For low-viscosity feedstocks used in LPIM, the rotational rheometer is a well-adapted technique for characterising the viscosity profiles during and after the injection stage. From a practical perspective, the viscosity at very low shear rates can be correlated with the feedstock's behaviour just after injection (i.e.,  $< 1 \text{ s}^{-1}$ , where the rotational speed of the rheometer is practically imperceptible). The viscosity at moderate or high shear rates (i.e., from 10 to  $1000 \text{ s}^{-1}$ ) is useful for predicting the feedstock behaviour during the injection stage [8]. Fig. 5(a) presents

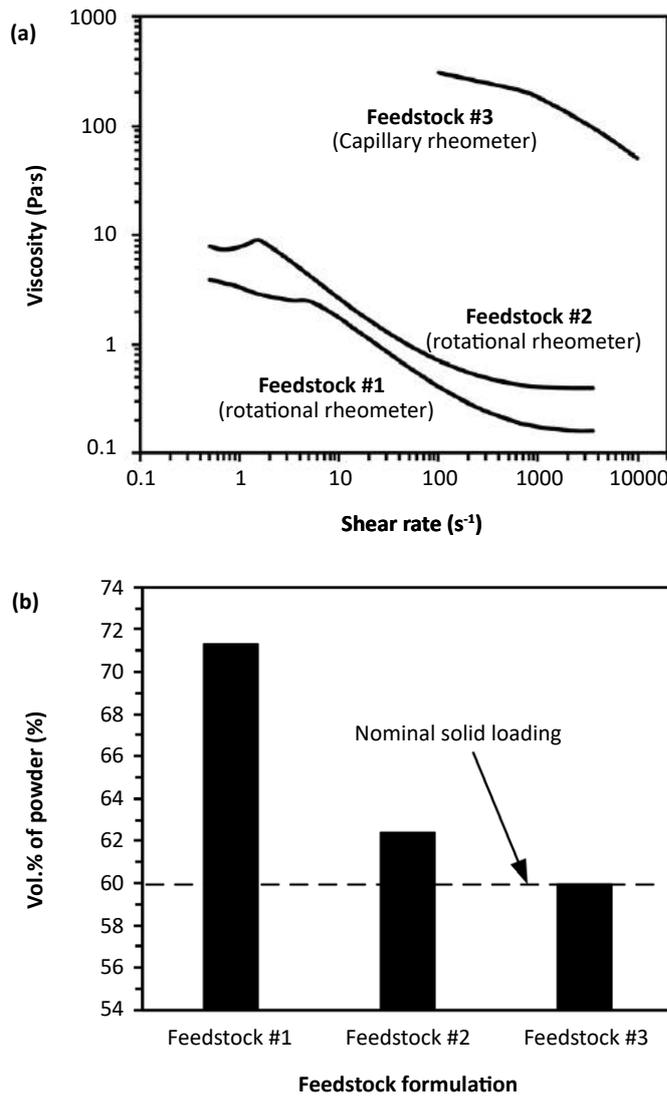


Fig. 5 (a) Viscosity profiles obtained by rotational and capillary rheometers, and (b) segregation values obtained by TGA technique after 10 minutes in molten state for typical LPIM feedstocks (17-4 stainless steel powder at 60% solid loading where feedstock #1: paraffin wax + surfactant; feedstock #2: paraffin wax + surfactant + small quantity of thickening agent; feedstock #3: paraffin wax + surfactant + large quantity of thickening agent)

typical viscosity profiles obtained with three different feedstocks. The viscosity decreases with the shear rate corresponding to the shear thinning behaviour generally required for any conventional PIM or LPIM feedstocks. This behaviour is explained by a particle or binder molecule orientation and ordering with flow promoting the decrease in flow resistance with an increase in shear rate. As a rule of thumb, a viscosity lower than 20 Pa·s is generally required to fill an intricate mould

cavity with LPIM feedstock [31-33]. In this respect, feedstocks #1 and #2 presented in Fig. 5(a), can be seen as two good feedstock candidates for the LPIM process.

To precisely quantify the rheological behaviour of such low-viscosity feedstocks, a test duration of a few minutes must be used to avoid segregation during the test [34]. Conversely, feedstock #3 presented in Fig. 5(a) exhibits a high viscosity value over all the shear rate range that can be used instead in

Medium- or High-Pressure Powder Injection Moulding. Note that this high-viscosity feedstock was characterised using a capillary rheometer which is well adapted to measure the viscosity at very high shear rates, but not really suitable for characterising viscosity values at low shear rates. Indeed, LPIM feedstocks cannot generally be characterised using a vertical capillary rheometer, because the low-viscosity mixtures flow by themselves under the gravity.

The segregation of feedstock is generated by gravity, an improper mixing method, high-shear rate variation, and a high pressure gradient before or during the moulding process. Segregation occurring in a powder-binder mixture has only been superficially examined in High-Pressure PIM due to the inherently high viscosity of feedstocks, which prevents the occurrence of this phenomenon. The segregation intensity can be quantified using density, heat capacity, thermal conductivity, electrical conductivity, thermogravimetric analysis, rheology measurements or microscopic examination [26, 27, 35-41]. It was demonstrated that the variation in solid loading through a moulded part can be measured with a sensitivity of +/- 0.25 vol.% [42], where all values outside this range indicate powder segregation within the feedstock (e.g., 60.0% +/- 0.25% in Fig. 5(b)).

In general, segregation must be avoided to prevent distortions, cracks, voids, warping and heterogeneous shrinkage during the sintering stage. In this respect, feedstock #3 presented in Fig. 5(b) can be considered as the best feedstock candidate in terms of segregation. However, its very high viscosity (Fig. 5(a)), related to the use of a large quantity of thickening agent, directly limits its mouldability and, in turn, its capacity to produce intricate parts. Conversely, feedstock #1 presented in Fig. 5(b) exhibits a high potential to segregate (i.e., 11 vol.% higher than the nominal value, indicating a powder-rich zone), but also a high mouldability capability anticipated by the very low viscosity reported in

Fig. 5(a). This feedstock could be difficult to control in production due to the requirement for very short injection sequences and no dead time in molten state.

From a practical perspective, a small quantity of thickening agent is often added to LPIM feedstocks in order to control the segregation while producing acceptable rheological properties, as illustrated in Fig. 5(b) with feedstock #2, where a few hundredths up to a few percent can be acceptable according to the specifications of the application. If no segregation can be tolerated, more thickening agent can be added to adjust the viscosity between feedstocks #2 and #3 presented in Fig. 5(a), while producing no segregation, such as in feedstock #3 reported in Fig. 5(b). For the LPIM process, the quantification and management of the interaction between mouldability and segregation remains a challenge (specifically for segregation generated by gravity, which has only been somewhat studied), where the full mouldability potential is still limited by the addition of thickening agent required to prevent feedstock segregation.

As illustrated in Table 3, mouldability and segregation are antagonistic parameters linked to the rheological behaviour of the feedstock. On the one hand, using a very low viscosity feedstock should allow the mould cavity to be easily filled, but this would also lead to a heterogeneous distribution of powder within the injected part. Indeed, this segregation may occur for low-viscosity feedstocks that remain idle within the injection machine due to gravity (e.g., into the injection channel), or that are subjected to complex shear rate gradients during injection. On the other hand, using a very high viscosity feedstock should avoid segregation, but would significantly reduce the moulding capability of the mixture (e.g., feedstock #3 in Fig. 5). Therefore, an ideal feedstock viscosity minimises segregation without compromising its mouldability.

Feedstock viscosity	Mouldability	Segregation
Too low	↑	↑
Too high	↓	↓
Ideal	Maximised	Minimised

Table 3 Antagonistic effect between mouldability and segregation

### Debinding and sintering approaches used in LPIM

Since each powder-binder combination requires its own specific debinding and sintering cycle, this section only proposes general guidelines about these two process stages. In HPIM, the use of primary and secondary binders provides several debinding strategies including thermal, solvent, or catalytic approaches, where the low-molecular weight constituents and the backbone polymer are extracted in two different steps. During the first step, the primary binder is removed at low temperature (e.g., using solvent or wicking debinding) to create open channels. During the second step, the role of the secondary binder is to maintain the shape up to the beginning of the solid-state diffusion of the powder (i.e., pre-sintering), where the remaining binder is burnt out and

debinding for LPIM components. Specifically, the green parts are embedded into a wicking powder bed (e.g., alumina, graphite, silica clay, zirconia or other inert powder) before being thermally debound under protective atmosphere. The role of the wicking media is to withdraw the liquid binder by capillary force (i.e., the carrier, the surfactant, and the thickening agent at the same time), as well as to maintain the shape up to the pre-sintering of powder particles.

Differential scanning calorimetry (DSC) and thermogravimetric analysis (TGA) are techniques that are well adapted for measuring the melting point and temperature range for binder burnout. These values can then be used to design a debinding cycle. On the one hand, a DSC graph recorded during a heating cycle (ASTM D3418) exhibits different peaks representing the melting point of each constituent, where the last

***“ Since LPIM feedstocks do not contain such backbone polymers, all binders are generally removed in just one step using wicking debinding - only a few research teams propose solvent debinding for LPIM components.”***

removed by the open pores formed during the previous step. Since LPIM feedstocks do not contain such backbone polymers, all binders are generally removed in just one step using wicking debinding – only a few research teams propose solvent

characteristic peak (identified as  $T_m$  in Fig. 6[a]) is the melting point of the feedstock, providing the minimum temperature for the mixing, the injection, and the debinding plateau. On the other hand, a TGA curve (ASTM E2550) shows the evolution of the

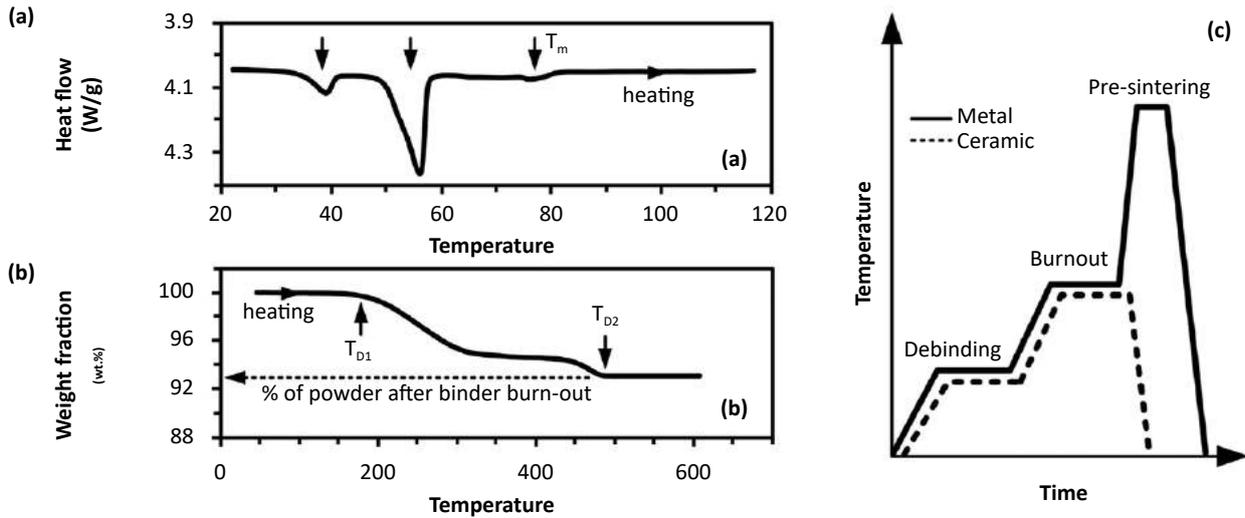


Fig. 6 (a, b) thermal properties of wax-based feedstock obtained by DSC and TGA techniques, (c) typical debinding cycle

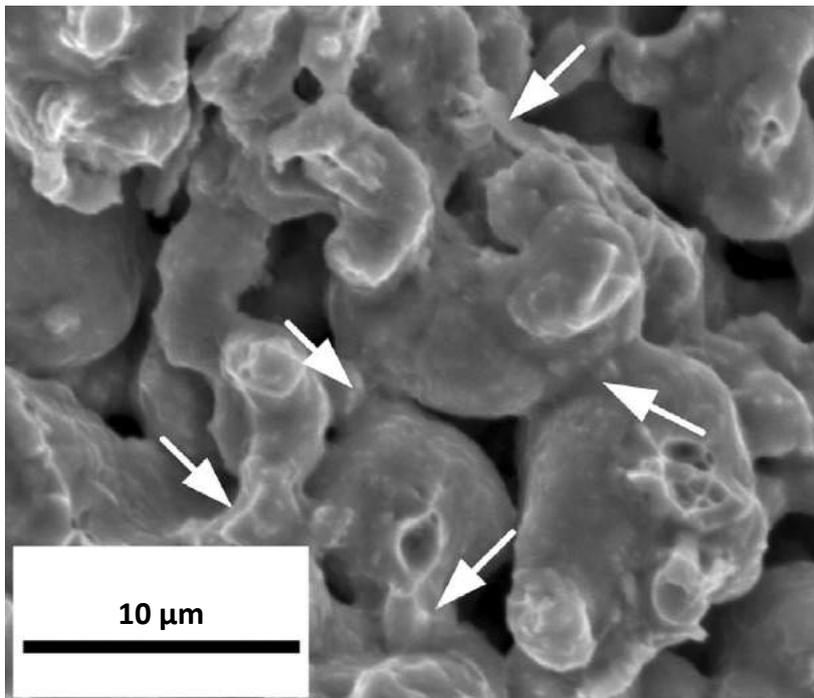


Fig. 7 SEM micrograph of a stainless steel after debinding, with white arrows highlighting particle bonds

feedstock weight during a heating cycle, where the change in weight fraction represents the temperatures for weight loss start and weight loss end (identified as  $T_{D1}$  and  $T_{D2}$  in Fig. 6(b)). These values can thus be used to define the debinding and burnout plateaus (Fig. 6(c)). As a rule of thumb, the temperatures for the debinding plateau range from  $T_m$  and

$T_{D1}$  (or are sometimes higher than  $T_{D1}$  to initiate degradation of some waxes), while the temperature for the binder burnout is higher than  $T_{D2}$ . After debinding, the debound part (also called the brown part) can be handled thanks to the activation of different mechanisms including pre-sintering of powders, cross-linked carbonaceous residues preferentially

located at the contact points of the particles, light oxidation sticking the inter-particle joints, or interparticular friction [43, 44]. During debinding of metallic-based feedstocks, all these mechanisms may occur, but pre-sintering and interparticular friction of powders are preferred, while the formation of carbonaceous residues or oxides is minimised. In this respect, the debinding cycle includes a pre-sintering plateau under protective atmosphere following the burnout plateau (e.g., black line in Fig. 6(c)) to produce particle bonds, as illustrated by white arrows in Fig. 7. Since ceramic powder cannot be pre-sintered or oxidised at low temperature, the minimal strength required for handling the part arises from the formation of cross-linked carbonaceous residues preferentially located at the contact points of the particles and/or interparticular friction of powder. For both metallic and ceramic-based feedstocks, the debinding cycle of an LPIM component that typically weighs a few hundred grams may take from dozens of hours to several days to avoid defects.

After wicking debinding, the brown parts are gently removed from the embedding powder bed, cleaned of all wicking media, and finally sintered at high temperature.

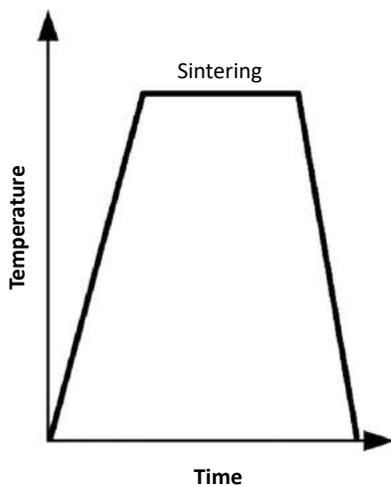


Fig. 8 A LPIM typical sintering cycle

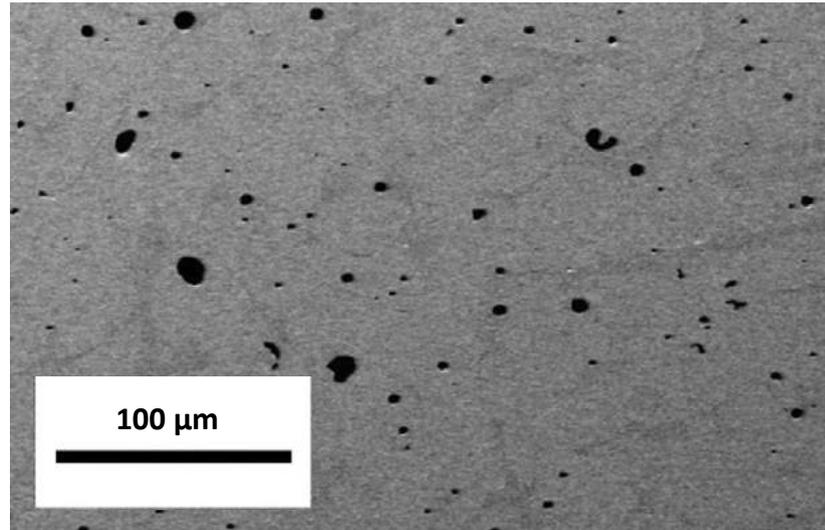


Fig. 9 SEM micrograph of a stainless steel after sintering

The sintering stage for LPIM and conventional PIM processes are very similar. The parts are heated up to a temperature slightly lower than the melting point of the powder under vacuum, inert or reactive atmospheres to control surface reaction and produce a well-developed grained microstructure. For example, the stainless steel feedstock presented in Fig. 3 (b) was debound under argon (see Fig. 7), and finally sintered at 1380°C for a period of 90 minutes under vacuum using a typical sintering cycle as shown in Fig. 8 to produce a dense and continuous metallic material (two shades of light grey in Fig. 9 representing alpha and delta ferrites), in which porosities represented by black marks are generally spherical and homogeneously distributed within the part.

## Conclusion

Low-Pressure Powder Injection Moulding is an emerging technology that, in particular, enables the cost-effective small series fabrication of complex-shaped ceramic and metallic parts with the proper dimensional tolerances. There is no doubt that the industrial and academic development of this process will bridge the gap

in knowledge on mouldability, segregation, and in-service mechanical properties in order to propose advanced manufacturing approaches for the production of intricate parts.

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# The globalisation of the Powder Injection Moulding industry evident at Hannover Messe 2019

For many decades, Hannover Messe has been, and still is, the world's leading industrial exhibition. From April 1–5, 2019, more than 215,000 visitors viewed the exhibits of 6,500 companies from all over the world. Dr Georg Schlieper visited the show on behalf of *PIM International* and talked to the representatives of a number of PIM related exhibitors on their booths. These interviews give some interesting insight into the current state of the industry.

The headline topics at this year's Hannover Messe were the use of Artificial Intelligence in industry and robotics, the potential of the new 5G mobile communication standard for industrial applications, lightweight construction and the future of work in a time of increasing digitalisation. For many visitors, the expected changes in industry as a result of climate change were also a focus of interest. Sweden was this year's partner country and, on the opening day, the Swedish Prime Minister Stefan Löfven and German Chancellor Angela Merkel toured the exhibition halls (Fig. 1).

Whilst Powder Injection Moulding may play only a small roll in the headline technologies, both leading international PIM players and small specialist producers regularly exhibit at the fair and this year was no exception. PIM technology was also represented in the media areas through the free distribution of copies of *PIM International* magazine. Approximately ten MIM and CIM manufacturers were

represented at the Hannover Messe in an area of the exhibition that focused on structural part manufacturing and *PIM International* took the opportunity to speak with them about their activities and the state of the industry.

## Sintex a/s

Sintex a/s, Hobro, Denmark, is a subsidiary of the Danish Grundfos Group and an established producer of pump and valve components by Powder Metallurgy technology for its



Fig. 1 Sweden's Prime Minister Stefan Löfven (right) and German Chancellor Angela Merkel visiting the show (Courtesy Hannover Messe)



Fig. 2 MIM sensor housings produced by Sintex (Courtesy Sintex)

parent company, as well as for the open market. Other markets served by Sintex include the automotive and medical sectors.

Sintex is also one of the most longstanding exhibitors of MIM technology at the Hannover Messe. With more than 150 employees, it also has business activities across hard and soft magnets, powder metal filters and surface technology. Examples of MIM products made by Sintex are the sensor housings shown in Fig. 2. According to Jan Graff, Sintex's Sales Manager, the most important recent innovation in his company is the use

of Additive Manufacturing for the production of mould inserts. These inserts, which can be produced in less than a week, are used for prototype tooling. With this technology, Sintex has reduced the time required for deliveries of injection moulded prototypes to only a few weeks.

Although the production facilities at Sintex are running at a high capacity, Graff sees significant potential for the further growth of its MIM business in the medical sector. One attraction, it was stated, are the higher profit margins in this area compared to those for automotive

components. In addition, he noted a number of new projects for Soft Magnetic Composites, which suggests a strong increase in the demand for these materials in the near future.

### Oesterle GmbH

The business of Oesterle GmbH, Röthenbach, Germany, is based on application development and technology support and the supply of metal structural components to its customers. The company does not have its own manufacturing capacity,



Fig. 3 Selection of automotive MIM parts marketed by Oesterle, from left to right: decorative weight, gear shift lever, brake foot lever (Courtesy Oesterle)

but rather purchases the goods from established and certified suppliers, mainly based in China. Approximately twenty-five people are employed by Oesterle.

In addition to MIM parts, Oesterle also offers investment castings, conventional Powder Metallurgy parts, and die-cast parts. The added value for the customer is that Oesterle assists in the design of the component, determining the dimensional tolerances, the choice of material and manufacturing process, as well as taking on large parts of the quality assurance process.

Oesterle stated that it maintains long-lasting relationships with its suppliers, thereby minimising supply chain risks. It also takes care of customs and freight, has storage capacities in Germany, and supports its customers in enabling just-in-time deliveries according to their needs. The majority of Oesterle's customer base is in Germany, Austria and Switzerland, but it also exports products to other European countries.

Dr Christian Hubert, Quality Manager at Oesterle, told *PIM International* that, in his opinion, the MIM market is growing faster than other market segments and MIM technology is therefore of prime importance to the company. A strong focus of Oesterle's marketing activities is in the automotive industry, thanks to the high production volumes required in this sector. Fig. 3 shows a selection of automotive applications marketed by Oesterle. Upon request, Oesterle offers training on the design and characteristics of MIM parts. This covers the special requirements of the PIM process and also considers the timescale required to reach the start of production for a new part.

## Maxon Motor GmbH

The PIM facility of the family-owned Maxon Group is located at Maxon Motor GmbH, Sexau, Germany, a specialist manufacturer of small electric drives and planetary gearboxes. These applications often

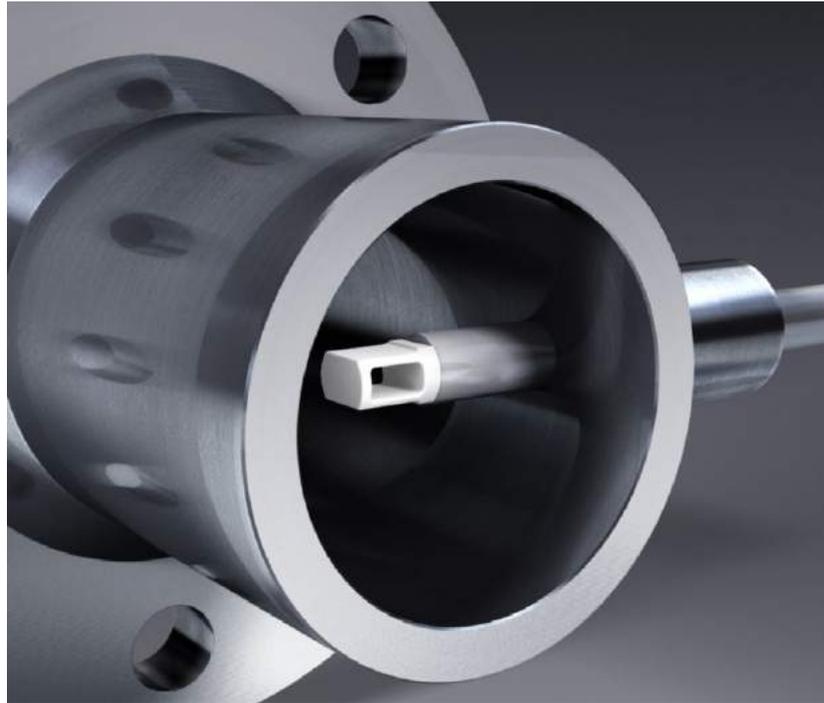


Fig. 4 Ceramic sensor casing made by Maxon Motor (Courtesy Maxon Motor)

contain small MIM and CIM parts which are manufactured in house. The factory in Sexau employs roughly five hundred people.

Besides electric motors and drives, Maxon produces CIM parts for many other industrial applications. Energy savings and the improvement of product quality are important issues in industrial processes. The precise measurement and control of many parameters involved in processing is required for this purpose. A ceramic sensor casing for measuring volume flows and flow rates of process gases plays a major role in this context. The requirements for the flow sensor are high; the sensor should deliver precise measurement results in different gases, high gas pressures and wide temperature ranges, even under the most difficult environmental conditions such as potentially explosive areas and in the open air. Another criterion when choosing the right sensor is to avoid high maintenance and follow-up costs. Maxon Motor's ceramic sensor casing (Fig. 4) serves to protect the sensor elements against the adverse environmental

conditions. The flow element is positioned aerodynamically in the sensor casing. Both the sensors for flow and temperature are installed within the sensor casing.

The sensor casing has a total length of 25 mm and a minimum wall thickness of 1.5 mm. In the application as sensor casing, it exhibits its resistance to high temperatures, abrasive dust in the gas flow and chemically aggressive condensate. The low heat conductivity of the zirconia ceramic protects the electronics inside the sensor casing. The use of electronic sensors is enabled by the passive behaviour of the zirconia ceramics towards electric and magnetic fields.

Maxon also produces microPIM parts for the Swiss watchmaking industry. Andreas Philipp, Head of the Business Unit Powder Injection Moulding, told *PIM International* that Maxon's latest innovation is a ceramic spring part for a wristwatch. With a wall thickness of less than 0.1 mm, the ceramic spring part is elastic like a steel spring. The advantage of the ceramic spring element is that it does not exhibit



## Rauschert GmbH

Rauschert GmbH, Pressig, Germany, is a group of companies that has been family-owned for 120 years. In addition to products made of engineering ceramics, Rauschert's factories produce high-quality plastic moulded parts, ignition systems and heating elements, as well as components for energy technology. It employs a total of about 1,200 people worldwide.

The company is one of the most renowned manufacturers of ceramic components by both CIM and other ceramic shaping technologies, and has a regular presence at Hannover Messe. Several plants in the south-east of Germany, the neighbouring Czech Republic and Poland are operated by Rauschert; their products are mainly used in textile machinery, sensor technology and analytical devices. A selection of typical CIM parts produced by Rauschert is shown in Fig. 5.

According to Ulrich Werr, Area Sales Manager, Rauschert's plant in the Czech Republic has started to manufacture labour-intensive CIM parts because a lot of manual work is often required in the production and the lower wages there help the business remain competitive. With some thread guides, it is unavoidable that the parting line of the mould cavity lies in the run of the thread. In these cases, the surface in this area must be carefully smoothed in the unsin-

tered state by hand and be completely defect-free. This, it is stated, is an extremely skilled task that only a few employees master.

Werr stated that Rauschert is constantly working hard on expanding and improving its production capacities. The injection moulding capacities of the German and the Czech plant have recently been enlarged and process automation has been continuously improved. The capacities for overmoulding ceramic parts with plastics have also been extended.

As far as the materials side is concerned, Rauschert can produce extremely fine-grained alumina with excellent wear resistance. The company has improved the purity of alumina to a value of better than 99.99%. Rauschert is also capable of producing translucent alumina, silicon nitride, yttria stabilised zirconia (Y-TZP) and magnesia partly stabilised zirconia (Mg-PSZ), both C230 and C221 type steatite, porous ceramics and MgO by CIM.

## Sembach Technical Ceramics

Another family-owned German ceramics specialist that has been in operation for more than a hundred years is Sembach Technical Ceramics, based in Lauf. Approximately 250 employees currently work for Sembach

producing high-precision parts from engineering ceramics via various forming processes such as extrusion, dry pressing and CIM. Applications for CIM parts are found in the automotive industry, mechanical engineering, household appliances, energy technology and textile machinery. Sembach's sales engineers support their customers in the development phase for new products.

In addition to products for technical applications, Sembach also produces decorative ceramic objects from zirconia with high-gloss black or white surfaces. Fig. 6 shows a white sensor housing made of Y-TZP partly stabilised zirconia, a thin white straightening rod from the same material, and a black sensor housing made of silicon nitride.

Prototypes, single piece and small-series products are manufactured by the machining of green preforms on a 5-axis milling machine and subsequent sintering. Depending on the material and application, the final treatment of the components may consist of polishing or hard machining. Grinding with diamond tools produces components with the highest precision. Both the most well-known ceramic materials, alumina and zirconia, as well as special ceramics such as silicon nitride and others are offered by Sembach.



Fig. 6 CIM parts produced by Sembach (Courtesy Sembach)



Fig. 7 Selection of MIM parts produced by Indo-MIM (Courtesy Indo-MIM)

### CeramTec Group

A truly global ceramics enterprise that also dates back more than a hundred years, the CeramTec Group is headquartered in Plochingen, Germany. More than 3,500 employees are active worldwide at production sites in Europe, the US and Asia, manufacturing well over ten thousand different products, components and parts, from the widest range of engineering ceramics. Surprisingly, this renowned company has not built up its own CIM facility to date.

According to Dr Gert Richter, Head of Basic Development, the decision not to invest in CIM was taken some thirty years ago. This decision has recently been revised and now CeramTec is qualifying alumina and zirconia as well as silicon nitride for CIM processing. In Richter's opinion it is too early to talk about specific products or applications, but it will certainly be interesting to see when CeramTec releases its first CIM products.

### Indo-US MIM Tec Pvt. Ltd.

In terms of size, Indo-US MIM Tec Pvt. Ltd. is a PIM producer that is in a league of its own. The Indo-MIM group of companies, headquartered in Bangalore, India, is one of the biggest and most versatile MIM producers in the world. Historically, Indo-MIM began as a joint venture with a US company and produced mainly for the US market. Today, two MIM plants and an investment casting factory in India, plus a new MIM facility in San Antonio, Texas, USA, belong to the group, which has a total of around three thousand employees. Indo-MIM covers the full range of MIM and CIM materials and applications (Fig. 7).

Approximately 95% of Indo-MIM's production is exported, mainly to the US and Europe. With sales offices and representatives worldwide, Indo-MIM serves these regional markets with full technical support.

Kiran Kumar, Sales Manager for Europe at Indo-MIM, told *PIM International* that the company has in recent years achieved a strong position in the medical sector for MIM parts thanks to major investments over a number of years. The production of medical parts is completely separated from other production units. As these products



Fig. 8 Joint exhibition stands of the Chinese metalworking industry at Hannover Messe (Photo Georg Schlieper)

usually have to be sterile and free of dust, the cleanliness requirements for these parts are much higher than in the rest of production. The company's operations include cleanroom production.

### Chinese MIM companies exhibiting at Hannover Messe

The Chinese metalworking industry presented its capabilities in a group of exhibition stands at Hannover Messe (Fig. 8). Its motto 'Focus on Quality' clearly demonstrates that the Chinese industry is struggling to shake off its historic image of delivering lower quality parts – an image that is still present in the minds of many engineers. As a result, quality considerations have had an extremely high priority in China and the positive effects of this are evident. This is also true for the Chinese MIM industry.

The Chinese MIM companies exhibiting at Hannover Messe had a clear interest in expanding their business into the European MIM markets, specifically the automotive and medical sectors. This is driven by the fact that the competitive situation in China has become more difficult in recent years. The country's huge consumer electronics sector, which drove the rapid growth of the Chinese MIM industry over the past decade, has reached a state of saturation and it is unclear whether the demand for MIM parts will continue to grow, stagnate or decrease. To grow further, many companies are therefore looking to diversify into new international markets.

*PIM International* interviewed the stand personnel of three Chinese exhibitors. Surprisingly, the exhibitors we met in the community area of the Chinese metalworking industry were from relatively small businesses. The largest names in the industry were either not present or exhibited in other areas of Hannover Messe.



Fig. 9 Electric hair clipper parts made by MIM (Courtesy ZCMIM)

### ZCMIM Corporation Ltd

With eight years of MIM parts manufacturing experience, ZCMIM Corporation Ltd is a relatively young company. However, the facility holds all major quality and environmental management certifications such as ISO 9001 and 14001, as well as TS 16949. With two hundred employees and a shop floor area of roughly 8000 m<sup>2</sup>, the company produces more than 300,000 parts daily. Besides the standard equipment for MIM production, a special focus is placed on secondary operations such as coining and tapping to improve dimensional accuracy. An in-house PVD facility serves to apply hard, corrosion resistant and decorative surfaces.

Allysha Yuan, Sales Manager at ZCMIM, told *PIM International* that her company distinguishes itself by producing aesthetic MIM parts with very high densities and polished surfaces. Typical products of ZCMIM are stainless steel parts for mobile phones, watches, hair clippers and industrial robots. A selection of parts for hair clippers is shown in Fig. 9.

### Hunan Injection High Technology Co Ltd

Changsha, in the Central Chinese Province Hunan, is a centre of Powder Metallurgy in China. It is home to a number of renowned PM research institutions, such as Central South University, that have brought forth a considerable number of PIM companies. Exhibiting at Hannover was Hunan Injection High Technology Co Ltd, a spin-off of the Changsha Research Institute of Metallurgy. Since 2000, Hunan Injection has been producing MIM and CIM parts as well as conventional PM components with a workforce of 140 people.

Gloria Law, Marketing Manager of Hunan Injection, told *PIM International* that the current marketing strategy of the company is focused on the medical sector. Small components for surgical instruments are a specialty of Hunan Injection. Besides a range of stainless steels, Hunan Injection is also capable of manufacturing MIM parts in titanium.



Fig. 10 Selection of 3C parts made by MIM (Courtesy SYD)

## Shiyeding Electronic Technology Co Ltd

At the stand of Shiyeding (SYD) Electronic Technology Co Ltd, *PIM International* was welcomed by Amily Zhu and Ying Wu. The business of SYD is based on MIM technology, CNC machining and process automation, organised in three independent business units. The company has strong links to the Asian electronics industry, particularly in the 3C market, where the majority of its products are used (Fig. 10). Founded in 2012 as a design and manufacturing company for precision tooling, the company turned its activities to MIM in 2015 and used its precision machining competence to manufacture injection moulding tools.

Where the dimensional accuracy requirements of MIM parts can not be met after sintering, CNC machining is applied. Process automation, its third line of business, is also used in-house for efficient parts processing. SYD stated that it has developed customised automation systems for handling small series production parts.

The MIM facility of SYD is located in Kunshan, Jiangsu Province, in the Shanghai area. It is equipped with eight injection moulding machines,

three debinding ovens and four vacuum furnaces. Of the more than 450 people employed by SYD, one third work in MIM production, with the rest in machining, automation and management.

## Conclusion

The exhibition in the structural parts section of Hannover Messe showed that the PIM industry is still growing, but there are also signs of consolidation in the market. Chinese MIM manufacturers, in particular, fear a decline in the 3C market and are looking for new fields of application for their technology, with the automotive and medical sectors at the top of their agenda. They know that the quality requirements are particularly high in Europe and are doing their utmost to comply with them.

European manufacturers are in turn feeling the increasing competitive pressure from the Far East and are trying to maintain their market position by constantly improving their technology and reducing their costs through investments in process automation. In the end, it is of course the PIM industry's customers who will benefit from this competition, with a growing and diverse range of high-quality, low-cost products.

## Author

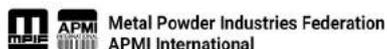
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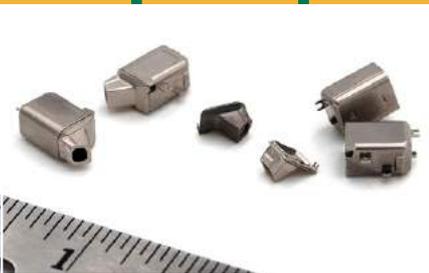
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# Lithoz: How Lithography-based Ceramic AM is expanding the opportunities for technical ceramics

The impact of Additive Manufacturing is today being felt far beyond the metal and plastics industry. This is particularly true in the world of technical ceramics, where processes such as Lithography-based Ceramic Manufacturing are opening up markets for new applications but also supporting technologies such as Ceramic Injection Moulding through the delivery of functional prototypes. In the following report, Isabel Potestio, from Austria's Lithoz GmbH, reviews the process, its parallels with CIM, and the opportunities that it presents for the ceramics industry.

The excellent properties of ceramics make them useful as components for a variety of applications, from industrial to medical. However, the ability to produce ceramic components with complex geometries and fine details can often be limited in Ceramic Injection Moulding because of the need for complex moulds. This in particular makes the production of parts in small series highly expensive. In addition, prototyping can be time consuming and customisation is impossible.

As a result, Additive Manufacturing is seeing increasing use in several areas as a solution which meets the increasing challenges faced by the ceramics sector. It enables the technological limitations of established ceramic processes such as CIM to be overcome and offers newfound design freedom as complex three-dimensional objects are produced layer-by-layer. AM therefore has the potential to transform the entire ceramic manufacturing value chain, as the optimal tool for adding value to products, operations, logistics and service, marketing and sales [1].

Early AM adopters, such as companies in the medical and aerospace sectors, are accelerating prototyping, exploring new designs that improve the function of products, and developing innovative and customised applications. In addition, companies are benefitting from a lean manufacturing chain with fewer production steps and

shortened assembly time. The time required for conventional production is thus reduced, as complex components can be produced all in one piece. The digital storage of additively manufactured parts also offers some innovative solutions in terms of stock management and delays in logistics.

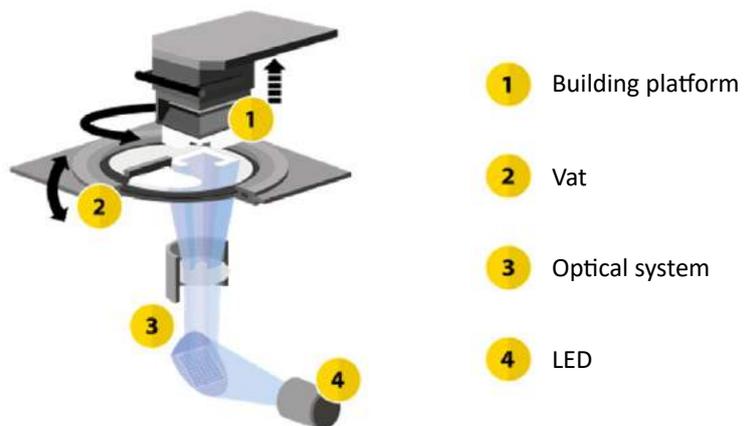


Fig. 1 Schematic illustration of the operating principle of CeraFab LCM systems. The arrows indicate the moving directions of the building platform and the vat

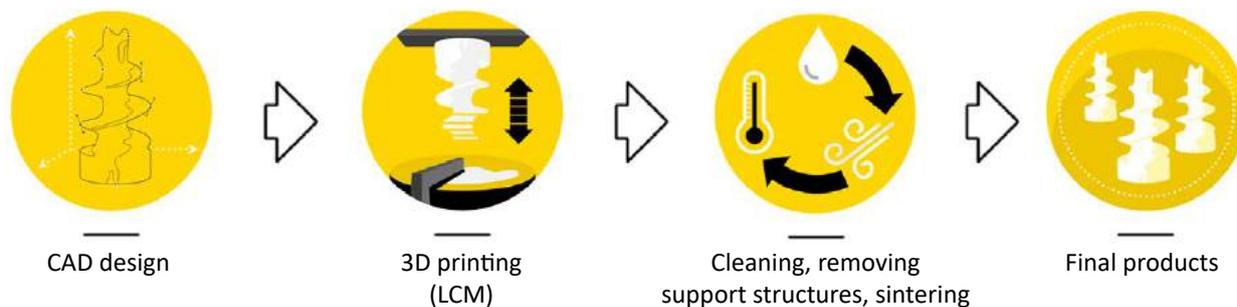


Fig. 2 The process chain for ceramic AM by means of LCM. The double-step approach of forming and thermal post-processing enables the production of high-performance ceramic parts that have similar properties to CIM

Whilst there are a wide variety of techniques for the AM of ceramics, success will always depend on identifying the right application in combination with the right technology. One of the most widely adopted methods for additively manufacturing high-strength, dense and accurate ceramics is Lithography-based Ceramic Manufacturing (LCM). This technology is well suited to ceramic applications where high precision and accuracy are required in combination with density and mechanical performance, similar to Ceramic Injection Moulded parts.

This article describes the LCM process developed by Lithoz and compares it to both Ceramic Injection Moulding and machining. In addition, the article highlights industries which have recognised these advantages early on, such as the casting and medical sectors, and how pioneers have employed lithography-based technology to develop functional applications.

### What is Lithography-based Ceramic Manufacturing technology?

Lithography-based Ceramic Manufacturing is a vat photopolymerisation technology in combination with Digital Light Processing (DLP) for forming three-dimensional objects layer-by-layer by the selective photopolymerisation of a ceramic-loaded liquid formulation.

As in all Additive Manufacturing technologies, the first step is the creation of a CAD model of the

part, which is used to prepare the build job. The job information is digitally transferred to the AM system direct from a computer. CeraFab machines, developed by Lithoz, allow for photocurable ceramic slurry to be automatically dosed and subsequently coated on top of a transparent vat. The movable building platform descends into the slurry, which is selectively exposed to visible light from below the vat. The layer image is generated via a Digital Micromirror Device (DMD) coupled to a projection system. By repetition, a three-dimensional green part can thus be generated layer-by-layer. A schematic illustration of a CeraFab system is shown in Fig. 1.

After building, the parts produced consist of ceramic particles embedded in an organic photopolymer network. Any excessive slurry must be removed from the surfaces and channels by cleaning the parts using compressed air and appropriate solvents, which are capable of dissolving the slurry without damaging the cured structure [2].

Subsequently, green parts have to be debound and sintered according to the requirements of the material used. From this perspective, LCM is very similar to any binder-rich ceramic forming technology and is similar to CIM or ceramic tape multilayer fabrication. Thus, following the conventional thermal treatment of the additively manufactured green bodies, theoretical densities above 99.8% are achieved and a homogeneous microstructure is developed [2]. Fig. 2 shows the steps involved in the AM of ceramics by LCM.

### A smart technology for fully-dense and high-performance ceramics

LCM meets the challenge of delivering fully-dense ceramic components with very good mechanical properties and surface finish in a highly precise and reproducible manner. The layer formation method typical for LCM has a number of significant advantages. Unlike other vat photopolymerisation methods, the parts are not submerged in the slurry, thus reducing the required amount of material needed to a minimum and avoiding the introduction of defects connected to interactions between the green parts being built and the mechanical coater.

Furthermore, this process reduces the operation of clearing the uncured suspension between submerged parts, as well as eliminating material recovery operations. Compared to laser-based build processes, where the point-by-point scanning of each layer's cross section is time consuming, the DLP device in the LCM system exposes the entire layer simultaneously, which decreases manufacturing times irrespective of shape, complexity or exposure area.

Besides a high-quality process and industry-oriented equipment, high-quality raw materials are needed to achieve properties comparable to Ceramic Injection Moulding. A broad range of ceramic slurries are available for LCM as standard materials: alumina, zirconia, silicon nitride, biodegradable  $\beta$ -tricalcium phosphate and hydroxyapatite (and mixtures of the two), as well as



Fig. 3 Investment casting cores manufactured from silica-based LithaCore 450 after printing and sintering, along with a cast metal part. The cores were produced on a CeraFab 8500 printer (Photo Manfred Spitzbart)

silica-based materials. For instance, the 4-point bending strengths for alumina and zirconia tested according to DIN EN 843-1 are 430 MPa and 930 MPa, respectively, whereas the 3-point bending strength for silicon nitride is 940 MPa.

In addition, alumina-toughened zirconia and zirconia-toughened alumina, together with cordierite, magnesia, glass ceramics, piezo- and transparent ceramics have successfully been processed using LCM.

### Key drivers, early adopters and cutting-edge innovations

There are several key drivers for the increasing adoption of ceramic AM technologies. The freedom of design allows engineers to develop value-driven applications, which increase efficiency and provide additional functionality of products. The supply chain can benefit from increased flexibility as designs can be quickly changed, prototypes can be rapidly

tested and re-adapted, tools can be digitally stored and complex part assemblies can be manufactured in one piece, avoiding assembly steps and reducing overall production costs and time.

The following examples highlight the diverse industry sectors which have recognised these advantages early on, and show how pioneers employ LCM to develop innovative functional applications and produce a broad range of different geometries, ranging from parts with fine and delicate features to relatively large and bulky parts.

#### Ceramic casting cores

In the aeronautical and industrial gas turbine market, typical applications of AM casting cores include cores for turbine blades made from nickel-alloys in single crystals (SX) and directionally solidified (DS) and equiax-cast (EX) materials. In this context, LCM offers a solution for different needs. Of utmost importance, LCM is effectively

used for the production of the most recent casting core designs. These have multiple layers of cooling channels, which can no longer be produced by Ceramic Injection Moulding. Ceramic casting cores, with complex branching structures and trailing edges with thicknesses smaller than 200  $\mu\text{m}$ , can now be produced with outstanding dimensional reproducibility and accuracy.

Furthermore, LCM is a toolless manufacturing process and thus offers a fast and low-cost production method for prototypes and small-scale series. It bypasses the costly and laborious fabrication of moulds required in Ceramic Injection Moulding, ultimately delivering a significantly faster time-to-market in combination with a shorter product life cycle. Ceramic Injection Moulding requires a mould for each product variant and, in the case of casting cores, this typically involves investments in the order of tens of thousands dollars and lead times of several months [3].



Fig. 4 (a) A patient-specific hydroxyapatite implant for treating bone defects in the mandibulum (lower jaw) (Design courtesy Michael Bergler, University of Pennsylvania, USA) (b) Patient-specific bioceramic implants and scaffold for applications in cranio-maxillofacial surgery can be produced out of medical grade bioceramics (alumina, zirconia, hydroxyapatite,  $\beta$ -tricalcium phosphate and mixtures) by means of LCM (Photo Sebastian Geier)

LithaCore 450 is a silica-based material used for the production of casting cores by LCM. The material was specifically developed for the AM of ceramic cores with fine details and high accuracy. Sintered ceramic cores made from LithaCore 450 have very low thermal expansion, a high porosity and outstanding surface

quality ( $R_a < 3 \mu\text{m}$ ), ensuring that internal channels in the final cast alloy have a smooth finish and good leachability. In addition, results from dimensional inspections performed on cores printed by LCM reveal maximum deviations  $< 0.1 \text{ mm}$  from the CAD model, which is within the expected dimensional compliance

for casting core application. Fig. 3 shows printed and sintered cores formed using LCM.

#### Medical and dental

Whilst CIM has made progress in recent years in the development of implant applications, because of the nature of the process these parts are restricted to standard sizes. Medical data generated from patients are, however, unique for every individual; the geometrical flexibility that AM provides makes it an obvious route for generating patient-specific products from patient data. Thus, the dental and medical industries have been amongst the earliest adopters of ceramic AM. As early as 2017, ten successful cranio-maxillofacial surgical procedures were performed using bioresorbable ceramic implants produced using LCM.

In dentistry and cranio-maxillofacial reconstruction, various ceramic materials are used for different clinical situations and ceramic AM is contributing significantly to various fields such as prosthetics, implants and surgical instruments. In bone-tissue engineering, AM allows for the production of interconnected porous scaffolds with defined geometries



Fig. 5 In dentistry, LCM allows for the production of full ceramic crown, ultra-thin occlusal veneers for minimal invasive reconstruction and endosseous screw-type dental implants. Fine edges down to  $100 \mu\text{m}$  can be achieved

and sizes, which facilitate the ingrowth of bone from adjacent tissues, as can be seen in Fig. 4(a) and (b) and Fig. 5 [5].

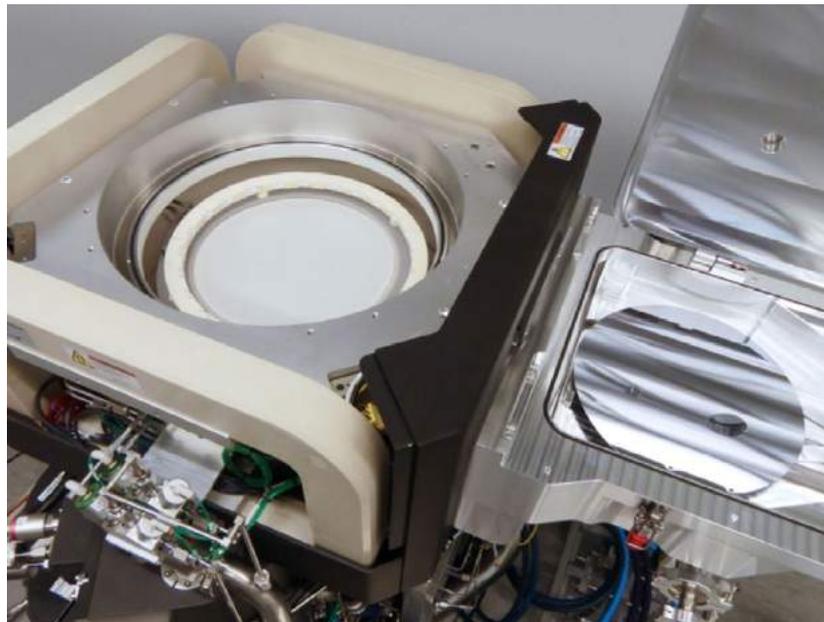
A range of medical grade materials is available, from the inert to the bioresorbable. Each material has been developed specifically for LCM. Inert ceramics such as alumina and zirconia offer a mechanically stable metal-free solution for dental implants, crowns and load-bearing bone defects. These materials do not release their components into the human body nor generate an antibody response and thus the success rate is expected to be higher than for metal implants.

Bioresorbable ceramics, such as  $\beta$ -tricalcium phosphate and hydroxyapatite/ $\beta$ -tricalcium phosphate mixtures, in the form of 3D interconnected structures, are a smart solution for the regeneration of bone defects. These materials exhibit the added value of stimulating bone ingrowth and are gradually degraded while being replaced by the natural bone tissue.

### Industrial and machinery

One of the major advantages of ceramic Additive Manufacturing is that it enables the production of designs that cannot be moulded or otherwise fabricated. This has offered several companies the opportunity of exploring new designs for improving the function of products and, thus, the development of value-driven applications.

Alumina Systems GmbH produces customised ceramic and metal-to-ceramic components for the semiconductor and medical industries. Besides conventional technologies, the company uses LCM to develop products with high added value for its customers. By using LCM, Alumina Systems GmbH, together with its project partner plasway-Technologies GmbH, developed a ceramic distributor ring for etching and coating of silicon wafers for semiconductor components for higher process productivity [Fig. 6].



*Fig. 6 Distribution ring with integrated ceramic AM nozzles (above). The distribution ring assembled in the Atomic Layer Deposition equipment (below) allows for 200% higher coating rate [Courtesy Alumina Systems GmbH and plasway-Technologies GmbH]*

LCM enabled the production of engineered nozzles with an optimised flow-path for gases. Such a component could not be produced using conventional manufacturing processes. The nozzles are integrated by means of soldering in a slip cast ring. This engineered solution allows for a significantly higher productivity rate (around 200% higher coating rate) with significant manufacturing cost reductions for the final user. This shows the major impact which AM can have when a value-orientated design approach is followed. When the added value is so significant, the cost of the product becomes far less important.

### Miniaturisation

The production of highly complex and precise ceramic components in the millimetre and sub-millimetre range requires a technology which can meet the demand for high degrees of both accuracy and repeatability. Established technologies such as Ceramic Injection Moulding, milling, drilling and grinding have limitations when it comes to very small or thin objects.

In the CIM process, one challenge is to achieve precise dimensional control over very small parts or features. The main obstacle is binder-powder separation, which can occur in the ceramic feedstock



Fig. 7 Sintered ceramic parts manufactured on a CeraFab 7500. The range of applications demanding high precision for small complex features includes industrial applications such as micro-nozzles and valves with flow-optimised paths, miniature rotors and micro-milling tools; electronic applications such as complex and precise substrates, sensors and instrumentation; and medical applications such as minimally invasive instruments and surgical tools (Photo Manfred Spitzbart)



Fig. 8 LCM for industrial serial production of AM ceramics: the CeraFab System. (Courtesy Lithoz GmbH)

due to high shear forces while flowing inside the mould. Generally, this results in non-uniform shrinkage and warpage of parts. In machining, it is extremely difficult to produce filigree parts, as edges and small details easily break off.

As LCM does not require a mould, there are no shear forces associated with flow into mould cavities, and a high level of dimensional control can therefore be guaranteed. Furthermore, since LCM employs a layer-by-layer building method, no cracks, fractures or edge chipping due to machining will occur.

In terms of applications requiring very small feature sizes, parts with walls and holes as small as 100  $\mu\text{m}$ , which also have a high degree of complexity and excellent surface quality, can be produced.

## Scaling up to serial production: process reliability and productivity

In recent years, the biggest development in ceramic AM has been the shift from prototyping to serial production. Today, the demand for value-driven applications is constantly increasing in sectors such as semiconductors, dental, medical and aerospace. This is resulting in multiple ceramic AM machines being delivered to customers, with production of more than a thousand parts per month now commonplace.

As industrial companies face permanent cost pressures, increasing the build speed and productivity of the AM process is a key factor in reducing production costs and accelerating the widespread use of AM ceramics on an industrial scale. With the AM of ceramics there is plenty of room for a significant reduction of manufacturing time and, consequently, costs. This can be achieved while still maintaining the desired level of product quality. Depending on the characteristics of the part, this is carried out by fine-tuning several settings.

In the case of high-volume production, a reliable technology is necessary. The reliability of AM of ceramics is dependent on a combination of factors – in particular, the system, software, material, printing process and the post-processing. All of these aspects need to be taken into consideration in order to guarantee consistency of customers' production and improve the output quality of their AM process.

The CeraFab System (Fig. 8) can incorporate up to four production units with an increased build speed compared to previous models, allowing for a significant increase in productivity. Furthermore, the CeraFab System fulfils the highest requirements regarding mechanical and dimensional accuracy and reproducibility of produced parts.

## Conclusion

LCM is today a complementary technology to Ceramic Injection Moulding. A wide spectrum of industries is applying LCM to the production of a broad range of different applications, ranging from fine and delicate miniaturised components to large casting cores, bioceramics and bioresorbable medical and dental implants.

The diverse industries which have adopted the AM process at an early stage are now shifting from prototyping to serial production, demonstrating that the demand of value-driven applications is constantly increasing.

Whilst there are inevitably areas where ceramic AM will impact on CIM, LCM technology presents many more opportunities for CIM firms to successfully deliver a wider range of components that do not have the past restrictions of low production volumes or the restrictions of mouldable geometries.

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# Xerion's Fusion Factory: A complete production cell for prototype and one-off 'PIM-like' parts

When it comes to using Additive Manufacturing to develop functional prototypes of MIM and CIM parts, Fused Filament Fabrication (FFF) is rapidly becoming a fast and cost-effective solution. Now, furnace specialist Xerion Berlin Laboratories GmbH, Berlin, Germany, has developed a complete system for the FFF of prototype and one-off metal and ceramic components. As Dr Uwe Lohse and colleagues explain, this modular system, which includes an FFF printer, solvent debinding unit and high-temperature furnace, offers PIM producers a technologically sophisticated solution to a long-standing sticking point for the industry.

The production of metal and ceramic components using Fused Filament Fabrication (FFF) is rapidly gaining traction for the production of prototype and small series parts [1]. The process is widely known in the plastics sector and there is, therefore, a great deal of motivation to use this process for the Additive Manufacturing of metal and ceramic components. Metal and ceramic filaments are now commercially available from various manufacturers, including Metal Injection Moulding and Ceramic Injection Moulding feedstock specialists, and post-processing after the build stage is similar to that used by the Powder Injection Moulding industry.

In addition, the investment costs of such systems are in some cases significantly lower than for those which use beam-based methods, such as Laser Powder Bed Fusion (L-PBF).

## FFF and PIM: Closely related technologies

In the FFF process, filaments which are closely related to conventional PIM feedstocks are pressed by an extruder through a heated nozzle and deposited in layers. Such

metal and ceramic powder-loaded filaments are significantly more difficult to handle than plastic filaments, and the necessary high degree of powder loading leads to increased brittleness. Powder loading ranges from 45–65% by volume, i.e. 80–97% by weight.



Fig. 1 A view of the complete Fusion Factory production line

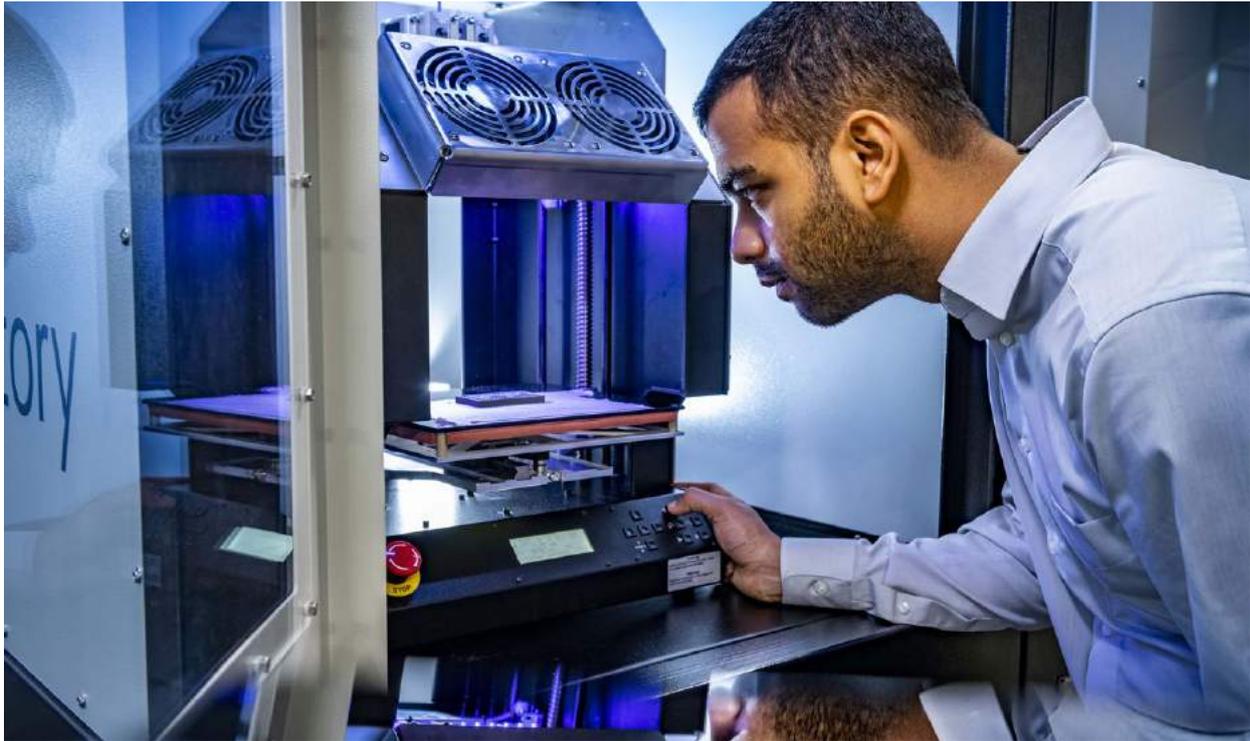


Fig. 2 Xerion's FFF module for metal and ceramic filaments

Typically, such metal or ceramic filaments are based on a composition that can be debound using acetone or a similar solvent. As with MIM and CIM, the green part – as it is called after the build process – is known as a brown part after debinding. Debinding leads to a decrease in strength; however, only a part of the binder material is actually released from the component, with the balance being thermally removed in the sintering process.

As with PIM, the sintering process consists of two steps. Residual binder is released at a temperature range of up to approximately 600°C. This must be removed from the furnace's processing chamber. From a temperature of around 600°C, the component consists only of metal or ceramic material that is then sintered in the usual way at much higher temperatures, typically above 1,300°C. In addition to temperature, the composition of the sintering atmosphere is decisive for the success of the process.

The main advantages of the FFF process are:

- Freedom from the tooling costs associated with MIM and CIM, but with the same metallurgical properties
- Cost-effectiveness compared to many other metal AM processes
- Short production times
- High degree of freedom for the production of multi-material components
- High Technology Readiness Level (TRL)
- 100% utilisation of the metal or ceramic powder used
- Infills and cavities easily produced

One factor that has held back the industrial use of the process is that no complete system has been available to date; individual pieces of equipment had to be purchased from different manufacturers. With the Fusion Factory, Xerion has now launched a complete system for the FFF of metal and ceramic components.

## The Fusion Factory's design

The aim when developing the Fusion Factory was to achieve a modular and industrially feasible design. The modular principle, with identical steel frames for each section, allows the simple addition or omission of individual modules. In particular, this means that to update individual units is a cost-effective future option. The industrial nature of the machine is underlined by its large steel frame, which protects the system from damage, especially during transport. Fixable rollers on the base, and crane lifting eyelets, simplify transportation and installation considerably.

The container-like configuration mirrors the machine's intended purpose – to quickly provide both functional prototypes and spare parts whilst placing the lowest possible demands on a facility's infrastructure. The use of the latest technology has resulted in reduced energy consumption, and an electrical connection of 400 V / 32 A (European version) places only a modest demand on an external power supply.

The system's build area of 150 x 150 x 150 mm makes it possible for MIM and CIM producers to manufacture prototype parts as well as one-off functional parts that can be significantly larger than those currently in high-volume MIM and CIM production. Initially, the focus is on ensuring process reliability for various materials within this specific build area. An extension of the maximum component dimensions is an integral part of future research and development.

### Production unit for green parts

The production unit for green parts is based on a commercially available FFF system which has been heavily modified in a number of significant areas. The system has two printheads that move in the y-axis, with the other two linear movements, in the x and z directions, performed by the heated print bed. The system is integrated in the modular steel frame, which is closed at the top with a door, resulting in an enclosed space (Fig. 2). The temperature in the build area is kept constant by an air conditioner system that is able to heat or cool as required, with temperature and humidity recorded and documented.

The main modification to the machine relates to the feed unit for the filaments. Metal and ceramic-filled filaments need the drive to be situated close to what is called the 'hot end' of the feeder, which ensures a feed with a lower surface pressure than is commonly used. In the Fusion Factory printer, this is achieved by a completely metal propulsion mechanism. Further modifications relate to the cooling management of the deposited layers, which have special requirements that are significantly different to those for plastic filaments.

A major advantage of the modified system is that the force on the nozzles between the feed and hot end can be measured. As a result, the system can monitor whether the force becomes too high, causing a risk of clogging, or whether there



Fig 3 The Fusion Factory's debinding unit

is no force at all as a result of filament breakage. The evaluation of this force via an automatically generated report is especially helpful for the further development of both the machine and new filaments.

The support mechanism for the filament rolls is ball bearing mounted and significantly reduces the force needed for unrolling. Simplify 3D® slicing software is used to generate the G-code.

### The debinding unit

The binder removal station was developed in-house by Xerion. The focus was on the requirement

that no explosion protection zone should be required outside of the production area; this was achieved using a hermetically sealed reaction vessel while constantly circulating the surrounding air volume within the unit during operation. All components used within the debinding unit are certified according to the ATEX directive and electrical signals are routed via isolation amplifiers.

The debinding system can run fully automatically; however, it is also possible to manually switch the actuators individually. This is particularly useful for research tasks and for servicing the system.



Fig. 4 The sintering furnace

The debinding process can be observed through a large sight glass and an LED light is also installed for this purpose.

The ability to adjust the fill level in the programme avoids the use of unnecessarily large amounts of solvents. Since the fill level is determined gravimetrically, solvents with different densities can be stored as a table in the control system. In the lower part of the unit, two containers, each with a capacity of 30 litres, are located on a removable tray. The fill level of the

container for used solvents is also recorded by a weighing system. If the canister for fresh solvent runs low, a warning is given.

The canisters are equipped with a quick-release system and, if necessary, can be replaced very quickly. The component to be debound can be loaded and unloaded easily via an overhead system. A sudden evaporation of the remaining solvent in the component after draining – which could cause cracks to form – can be avoided by allowing the

component to remain in the system for a fixed period – and possibly by reheating.

### The sintering furnace

The sintering furnace installed in the Fusion Factory is a multi-atmosphere system that allows the processing of a wide range of different metal and ceramic materials. It is designed as a cold wall furnace with internal heating and insulation system. The furnace chamber is made entirely of stainless steel and is double-walled and water-cooled on all sides.

The front door, together with the furnace hearth, can be moved back and forth in a linear manner. This drawer principle is both ergonomic and ensures that the inside of the furnace, including the sensitive insulation, is protected against damage (Fig. 4). Fitted with cermet heating elements, the furnace can operate at up to 1,500°C in 100% hydrogen (dew point +20 - +10°C), nitrogen, vacuum up to 10<sup>-4</sup> mbar, and air.

During sintering, the component is placed inside a ceramic retort during the furnace run. During rest debinding at up to around 600°C, the gas flows from the outside into the retort and is constantly pumped out through an opening in the floor. This prevents fouling of the furnace cavity with binder residue and improves the debinding process. At temperatures above 600°C, the flow direction reverses within the retort and fresh gas flows directly into the retort via the floor, helping to keep contaminants away from the part.

Temperature regulation is extremely accurate and, at a static temperature, the deviation from target is less than ± 0.5 K. The programme for fully automatic operation is comprised of up to twenty time segments and up to ninety-nine programmes with numbers and names can be stored.

Since both flammable and oxidising gases can be used, a wide range of safety measures are required. A fail-safe programmable logic controller (Siemens S7-1500) forms the core of the safety management system, while additional



Fig. 5 User interface of the 42 in touch screen

Printer unit	Debinding unit	Sintering unit
<ul style="list-style-type: none"> <li>• Temperature in build volume</li> <li>• Humidity in build volume</li> <li>• Print bed temperature</li> <li>• Temperature Nozzle 1</li> <li>• Temperature Nozzle 2</li> <li>• Force at the nozzles</li> </ul>	<ul style="list-style-type: none"> <li>• Solvent filling level in reactor</li> <li>• Solvent temperature</li> <li>• Temperature heater</li> <li>• Setpoint temperature</li> <li>• Gas flow nitrogen</li> <li>• Pressure in reactor</li> <li>• Solvent filling level in canister</li> <li>• Fan on / off</li> <li>• Top door open / closed</li> <li>• Bottom door open / closed</li> </ul>	<ul style="list-style-type: none"> <li>• Temperature heater</li> <li>• Temperature sample</li> <li>• Heating power</li> <li>• Setpoint temperature</li> <li>• Gas flow nitrogen</li> <li>• Gas flow air</li> <li>• Gas flow hydrogen</li> <li>• Pressure in vessel</li> <li>• Vacuum in vessel</li> <li>• Door open / closed</li> <li>• Clamps open / closed</li> <li>• Vacuum pump on / off</li> </ul>

Table 1 Overview of the displayed and saved system data

sensors detect pressures, temperatures and gas compositions. The exhaust gas is passed through a flaring device, where the flame is monitored continuously with a high-voltage ionisation sensor. An additional source of inert gas, usually an extra gas cylinder, is necessary and is also constantly monitored.

Before a hydrogen atmosphere furnace run can be started, the furnace is conditioned by a pre-processing function. Among other things, this tests for leaks at excess and negative pressure. Furthermore, a check is made of all sensors and connected media. After completion of the sintering run, a post-processing function is carried out in which the chamber is again evacuated and refilled with fresh gas. Once the temperature has fallen below the removal temperature, there is no danger to the operator from the escape of residual gases from the sintering process.

The furnace system can optionally be specified to aerospace standard AMS 2725E. This standard includes additional requirements

for the detection of temperature homogeneity and the accuracy of temperature measurements, as well as defining the need for data storage in a tamper-resistant data format. Xerion has many years of experience in this field and has already equipped a large number of furnaces to meet this standard.

### The control unit

The control unit covers the control of the entire Fusion Factory and has at its heart a fail-safe industrial controller, the Siemens S7-1500. It is operated via a 42" touch screen (Fig. 5), the surface of which is made of safety glass, making it suitable for safe operation in harsh industrial environments. The extremely large surface gives the operator the ability to monitor the entire system, with the most important current parameters being easily visible.

### Programmed operation

The control system enables the editing of the print parameters and the respective scheduling

programmes for the debinding and sintering units. In addition to numerical names, there is always the possibility to enter and save real names. The number of such programmes is unlimited. To edit programmes, a password is required and edited programmes can only be opened and executed by the operator, who must also enter a batch number, a batch name and their name.

### Report function

After each process step is completed, a report is automatically created that documents the most important parameters (Table 1). At the touch of a button, a PDF can also be created. A database makes it possible to recall historical data at any time, based on the batch number.

### Safety functions

Safety has been given the highest priority in the design of the control system. In addition to the safety features already highlighted, the system features an advanced alarm management system. All occurring alarms and warnings are displayed and archived. When an alarm occurs,



Fig. 6 Rolls of metal and ceramic filaments in stock at Xerion

Material	Sintered material properties	
	$\sigma_{rel}(\%)$	Carbon cont. (wt.%)
Supplier 1, 316L	98.4 ± 1.5	0.048 ± 0.003
Supplier 2, 17-4PH	98.9 ± 1.5	0.042 ± 0.004

Table 2 Properties of metal components (Courtesy Fraunhofer IFAM Dresden 2019)

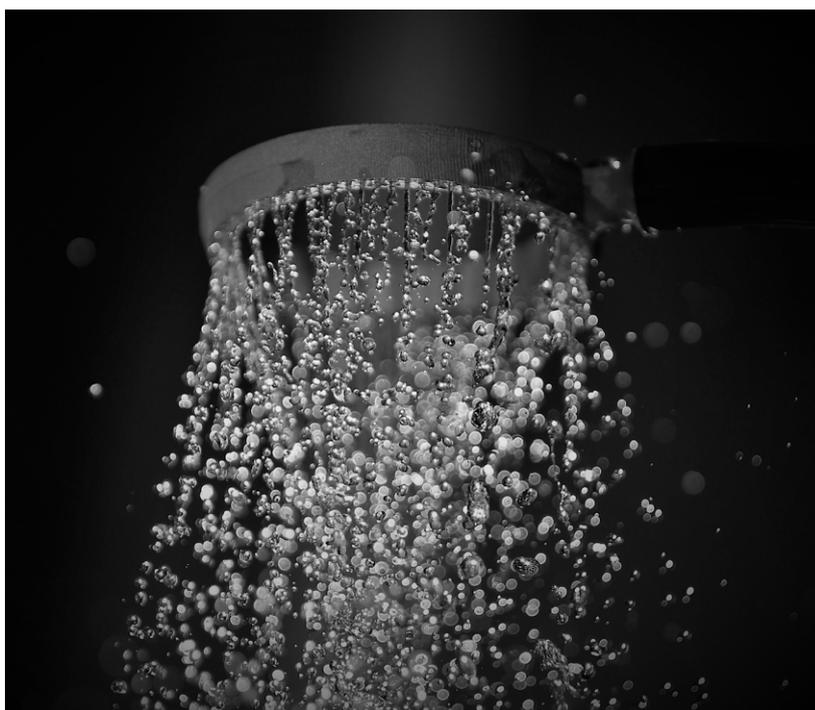


Fig. 7 Shower head ring produced using Xerion's Fusion Factory (Courtesy Aloys F. Dornbracht GmbH & Co. KG)

the system automatically goes into a safe mode, facilitating unattended operation.

### Components produced in the Fusion Factory

So far, the materials processed using the Fusion Factory include 316L and 17-4PH stainless steels, tungsten alloy, aluminium oxide ceramic ( $Al_2O_3$ ) and Zirconia Toughened Alumina (ZTA). Fig. 6 shows a selection of in-stock metal and ceramic filaments. Other materials are commercially available in filament form and are currently in the testing phase. These include zirconium oxide ceramics in various modifications, tool steels and other refractory metals. Table 2 shows the density and carbon content of two stainless steel test specimens.

Initial measurements of the mechanical properties show that the manufactured components meet the requirements of MIM standard ISO 22068: 2014 [2]. Whilst the surface has the typical roughness associated with FFF printing, the haptic impression is much smoother than surfaces typically produced in the Binder Jetting process.

### Shower head ring

The 316L stainless steel shower head ring shown in Fig. 7, with an inside diameter of 48 mm, was produced using the Fusion Factory. The ring has a water channel inside and the outlet opening of each of the nozzles has a diameter of 0.9 mm. A special feature of this design is that the nozzles are arranged at different angles, so that the water is directed from the ring in different directions. As a result, this component would be very difficult to produce using conventional manufacturing methods.

Using FFF, the cavities were built without the need for any support structures. Only one extrusion nozzle was used and the required build time was about four hours. Debinding was carried out at slightly elevated temperature (42°C) for several hours in acetone.

The thermal debinding and sintering steps were carried out in the furnace in one go. Debinding was carried out in an inert gas atmosphere in vacuum operation, while the high-temperature sintering phase was carried out with reversed gas flow in a pure hydrogen atmosphere. The parts were sintered at 1340°C.

### Parts for high-temperature furnaces

As a machine manufacturer, it makes sense to produce parts that can in turn be used as components in the same system. This results in a machine that can produce its own replacement parts. Honeycomb panels with an 80 mm edge, which can be used for the furnace hearth, are an example of this. A furnace hearth produced in this perforated form allows for good heat transfer via radiation from an underlying heating element and an almost unhindered circulation of the process gases in the workspace.

The structure of these plates is particularly well suited for production via the FFF process, since they have a flat structure and the wall thicknesses are low despite their relatively large dimensions.

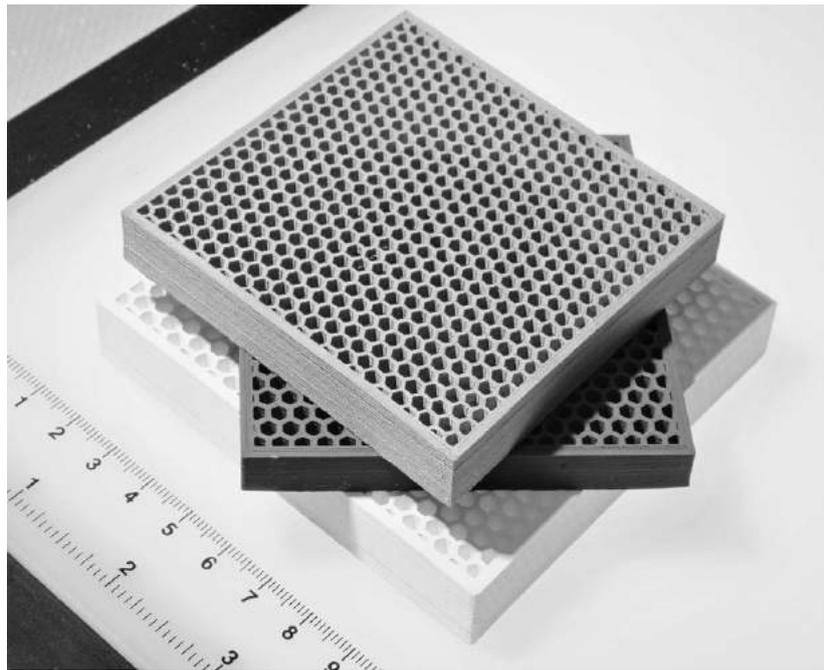


Fig. 8 Components for high-temperature furnaces (top: stainless steel 17-4PH, middle: tungsten alloy, bottom: ceramic Al<sub>2</sub>O<sub>3</sub>)

The honeycomb structure offers particularly high strength.

Fig. 8 shows a selection of these honeycomb panels produced in different materials. Particularly noteworthy is the ability to produce these plates using refractory metal, so that they can be used up to the highest temperatures in a protective gas and vacuum environment.

In addition to the production of plates for furnace hearths using FFF, the production of further furnace fittings is planned. These include retorts, thermowells and porous insulation.

### The design and manufacture of multi-material components

Filament-based production allows, in a unique way, the manufacture of



Fig. 9 Steel/ceramic multi material component during printing

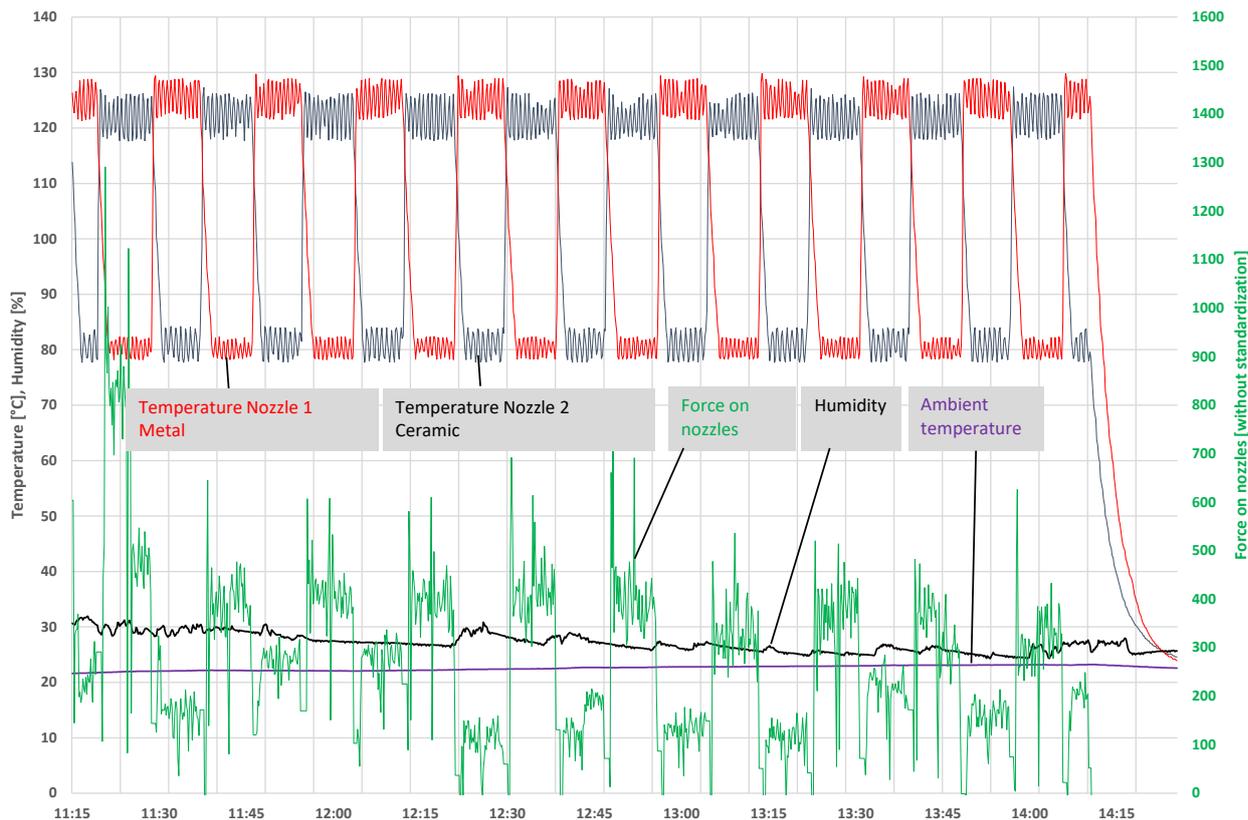


Fig. 10 Printing log for the multi-material honeycomb plate stainless steel 17-4PH / ceramic Al<sub>2</sub>O<sub>3</sub>

components made of two or more materials. Thanks to the nature of the process, there is significant freedom when designing the shape of the interface between the two components, rather than just being limited to a horizontal plane.

The conditions for successfully processing two materials are that they must possess almost the same sintering temperature, sintering shrinkage and thermal expansion. In the case of shrinkage, it must be considered that this parameter can be influenced by final porosity. Increased porosity is often an advantage in usage as a thermal insulator for ceramic components. Fig. 9 shows the production of a multi-material component (17-4PH / Al<sub>2</sub>O<sub>3</sub>).

Visible are the slightly different nozzle temperatures for the two components and the relatively strongly differing feed force, depending on the material and parameter setting. Opening the door for optical control of the build

process leads to a measurable increase in humidity in the installation space.

The combination 17-4PH / ZrO<sub>2</sub> has long been known to fulfil the three conditions mentioned above [3]. Further work will be aimed at applying this combination of materials to larger components. Fields of application are possible in many branches of industry. In particular, these include ceramic layers to protect metal components against corrosion and abrasion. Fig. 12 shows prototype metal plain bearings with ceramic bushes.

### What lies ahead for the Fusion Factory?

Xerion's Fusion Factory is a sophisticated tool for the production of metal, ceramic or multi-material components, either as prototypes or in small batches. For each manufactured component, a data record is generated that can

meet high quality assurance requirements. The nature of the process and the materials used make it particularly relevant for the MIM and CIM industries, where it is capable of playing an important role in the rapid prototyping of functional components.

The system presented here is an intermediate step, as the components are moved manually one by one from unit to unit. It is planned that future systems will offer automatic transport, with the components moved only in a dust-proof enclosure.

The open philosophy of the system allows the use of filaments from various manufacturers and, in the near future, this market sector is expected to develop strongly, so the range of materials available will expand significantly. The modular design of the system allows the addition of further units to the production line, such as scanners. In order to synchronise the production processes, it may

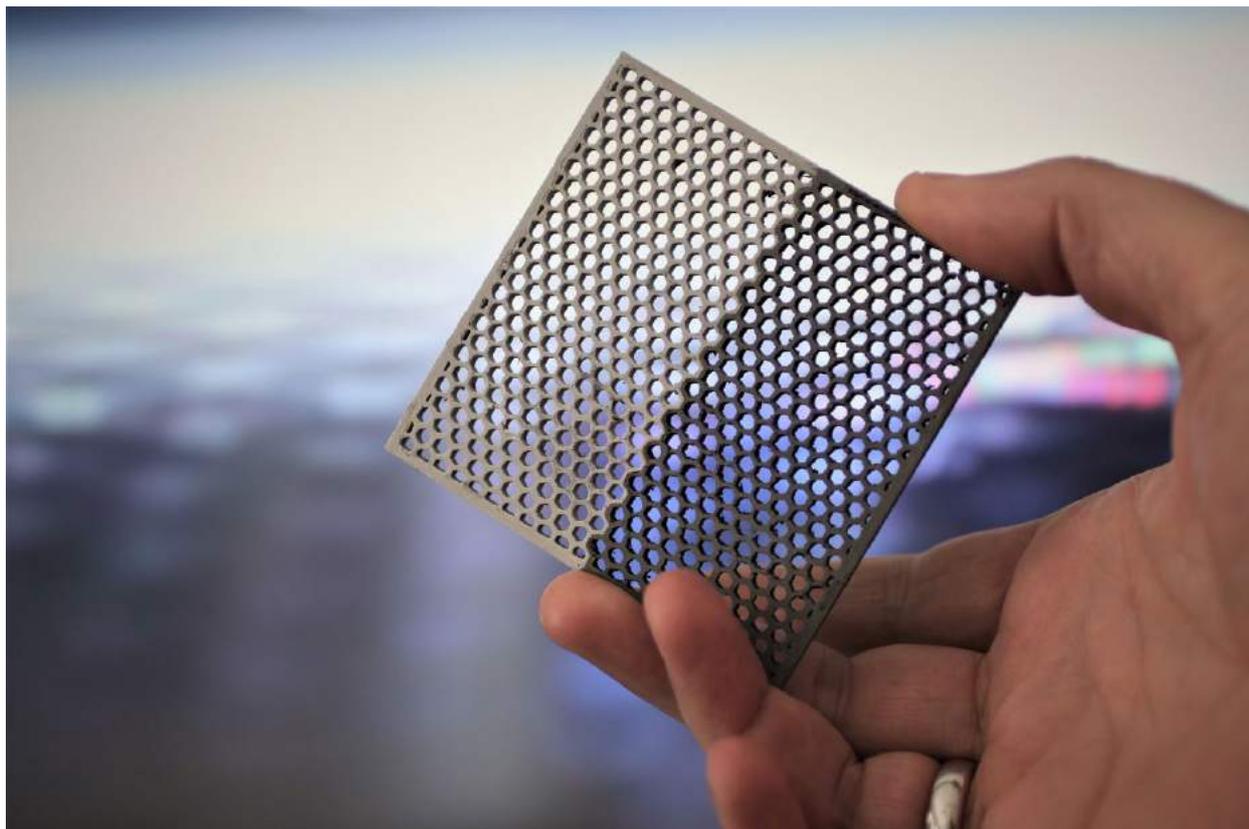


Fig. 11 A multi-material steel / ceramic (17-4PH / Al<sub>2</sub>O<sub>3</sub>) component produced by FFF

be useful, for example, to integrate additional furnace units, since this process step usually takes the longest time.

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Fig. 12 Multi-material components for plain bearings

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# Dry ice cleaning in Powder Injection Moulding: Theory, process and application

The cleaning of moulds is an essential task in a Powder Injection Moulding facility. The process can, however, be time consuming and risks damage or wear to critical surfaces and components. In the following article, Steve Wilson, Cold Jet LLC, Loveland, Ohio, USA, presents the advantages of using dry ice for mould cleaning. In addition to a reduced risk of wear or damage, environmental and economic and productivity-related benefits are outlined.

No matter what type of materials you are processing, moulds are a mission critical asset that require timely, proper and efficient maintenance - namely cleaning - to ensure uptime and part quality. One of the big challenges for the Powder Injection Moulding industry is the rapid frequency which moulds foul. Binders, particularly the base polymers, necessitate frequent mould cleaning, sometimes to the extent that an automated cleaning process may even be required. This article will detail the advantages of dry ice cleaning as a replacement for solvent and/or mechanical cleaning methods, outlining what dry ice is, how the cleaning process works and the primary reasons why many in the PIM industry have chosen to clean with dry ice.

The magic begins with the fact that dry ice disappears, it sublimates. What also disappears are the many moulding problems associated with dirty cavities and vents. Watching the dry ice cleaning process is practically magical, as the small particles of dry

ice sublimate and disappear and the substrates being cleaned reappear as clean as their original form.

## What is dry ice and where does it come from?

Dry ice is the generic name for the solid phase of carbon dioxide (CO<sub>2</sub>). While CO<sub>2</sub> is naturally found in our

environment, 95% of the CO<sub>2</sub> that is used to produce dry ice is reclaimed; it is an abundant by-product of numerous industrial processes such as distillation and petrochemical refining.

This by-product CO<sub>2</sub> is captured, purified and pressurised. Pressurising CO<sub>2</sub> to around 300 psi will phase it from a gas to a liquid. The liquid CO<sub>2</sub> is piped from a storage tank to a



Fig. 1 Dry Ice production equipment



Fig. 2 Top: 3.0mm dry ice pellets, below: 0.3mm particles



Fig. 3 Before and after image die steel showing no damage after blasting

dry ice production machine, such as the pelletiser shown in Fig. 1. While the size of the dry ice pellets produced in pelletisers can vary, the most common size used in mould cleaning have a diameter of 3.0 mm.

Injection moulders can purchase dry ice from a local gas company, which can establish a weekly delivery programme. It is typically delivered in a rotational moulded, insulated container, holding perhaps 250 kg of dry ice. The gas company will pick

up empty containers and deliver full ones as required. These 3 mm pellets can then be loaded into a blasting machine which is capable of blasting the full 3.0 mm pellets as well as being programmable to reduce the pellets into twenty-eight different smaller sizes (Fig. 2).

### How the process works

#### Impact

The dry ice cleaning process can be described using the acronym ICE – Impact, Cold and Expansion. Dry ice particles have a momentary kinetic energy that can be delivered to the contaminant on the mould surface. That energy can be described as the 'Impact' or the Kinetic Energy Effect, which is partially determined by the size of the blasting pellets.

The amount of energy being delivered ( $KE = 1/2MV^2$ ) is determined by both the particle size and impact velocity, or blast pressure. Particle size and velocity are both operator adjustable. For example, on the Cold Jet Model PCS 60, the full twenty-eight different particle sizes can be selected, ranging from 3.0 mm pellets down to 0.3 mm pellets. Blast pressures ranging from approx 130 kPa to more than 1000 kPa generate dry ice particle velocities up to around 365 m per second.

The larger 3.0 mm pellets are better for thick, stubborn contaminants on items such as injection screws, while the smaller 0.3 mm pellets are better suited to thin, brittle contaminants and delicate substrates. Your cleaning requirement may be for a pellet size somewhere in-between 3.0 and 0.3 mm. The air pressure is also correspondingly adjusted up or down to achieve greater cleaning capabilities.

A common question is: does the impact or the kinetic effect of the dry ice cleaning have a negative effect on the mould? This is the first reason why injection moulders are using dry ice cleaning – to

eliminate mould wear and damage as a result of cleaning. Dry ice cleaning will, in fact, extend the asset life of the mould, as demonstrated by an independent study conducted at Kettering University, Flint, Michigan, USA, on common die steel. Fig. 3 shows a blasted and un-blasted area of the die steel after blasting [stationary] for sixty seconds, at 90°, at a stand-off distance of 25 mm. The study concluded that, "the sample had no noticeable damage after blasting," when evaluated with a profilometer.

### Cold

The second principle to the dry ice cleaning process is the 'C' for Cold, or the Thermal Effect. Unlike other blast media, the dry ice particles have a very low temperature. This inherently low temperature gives the dry ice cleaning process unique, thermodynamically induced surface mechanisms that affect the adhesion of the contaminate to the substrate. This Thermal Effect is a unique characteristic of the dry ice cleaning process. While it is not cryogenic, it is extremely cold, at -79.5°C. The low temperature of dry ice aids the removal of contaminants as it causes them to embrittle and shrink, creating rapid micro-cracking and causing the bond between the contaminant and the substrate to fail (Fig. 4).

It has been shown that the contribution of the Thermal Effect towards the overall cleaning can be as high as 50% for objects heated to 500°C. While we will never get that hot, it does explain why cleaning moulds at operating temperatures is faster and easier; because the thermal contribution to cleaning is greater.

This thermal cleaning effect sometimes delivers another question: does the Thermal Effect of the dry ice cleaning process cause micro stress cracking on the moulds? One study has shown, using thermocouples embedded into a steel substrate at varying depths, that the temperature decrease occurs on the surface only, so there is no chance of thermal stress occurring to a metal

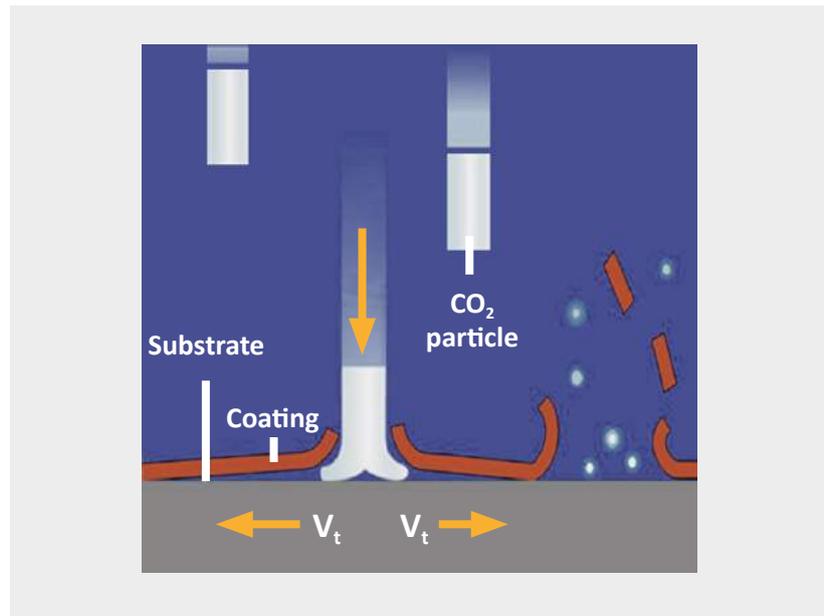


Fig. 4 The kinetic, thermal and sublimation properties of CO<sub>2</sub>

substrate. A dry ice particle stream was constantly swept across the test specimen for thirty seconds, a relatively long time for this process, and the thermocouple recorded the changing temperatures at the

Upon impact, dry ice will sublimate. It will phase from a solid back to a gas, volumetrically expanding up to 700–800 times in size. When doing so, it leaves no secondary waste. In essence, the impact micro cracks

*“... cleaning moulds at operating temperatures is faster and easier because the thermal contribution to cleaning is greater.”*

various depths. The study concluded that there was no thermal stress to steel in the hardened condition, primarily for two reasons. Firstly, the temperature gradient occurs at the surface. Secondly, the thermal stresses involved are much less than those encountered during normal heat treatment. When the stress was calculated, it was below the yield point of steel in the hardened condition.

### Expansion

The third cleaning effect is the 'E' – Expansion. This is another unique characteristic of dry ice cleaning.

the contaminant, the cold embrittles it causing it to shrink and lose its bond strength with the substrate, and the expansion blows the contaminant off of the substrate.

### Dry ice mould cleaning process in practice

The process begins by taking the dry ice blaster to the moulding machine. The machine requires compressed plant air, typically 30–50 cfm, and a 110 V electrical connection. Normal protective clothing for the operator will include gloves to handle the dry ice, safety glasses and ear plugs.



Fig. 5 Conventional baseline hexane aerosol cleaning



Fig. 6 Dry ice cleaning underway

Fig. 7 shows the 'before and after' of off-gassing on the vent area of the mould. Sometimes the cleaning frequency is so regular that the business case supports incorporating an automated mould cleaning system.

Tom Mendal, President of Performance Plastics in Cincinnati, Ohio, USA, uses dry ice to clean his moulds. He stated that using dry ice cleaning, "extends production runs by 200-500%, but safely cleans moulds hot [230°C] in the press or cold on the bench, preventing mould damage. This saves us from cooling the mould down, removing it, disassembling it, reassembling it, putting it back in and heating everything up. That is a lot of time – up to sixteen hours – and risks damage. We are sensitive to the extension of a production run and our start-up costs. Once we get something running, we don't want to stop."

Mendal explained that the speed of the cleaning process is also important. "We use it every day, on every shift," he commented, and referred to previous cleaning methods: "To clean it is to destroy it. Cleaning with Cold Jet will not roll parting lines or change or destroy the metal."

Dry ice helps extend the asset life of a mould due to the fact that dry ice is a stable, linear molecule that is non-polar. It does not possess a positive or negative charge, so it does

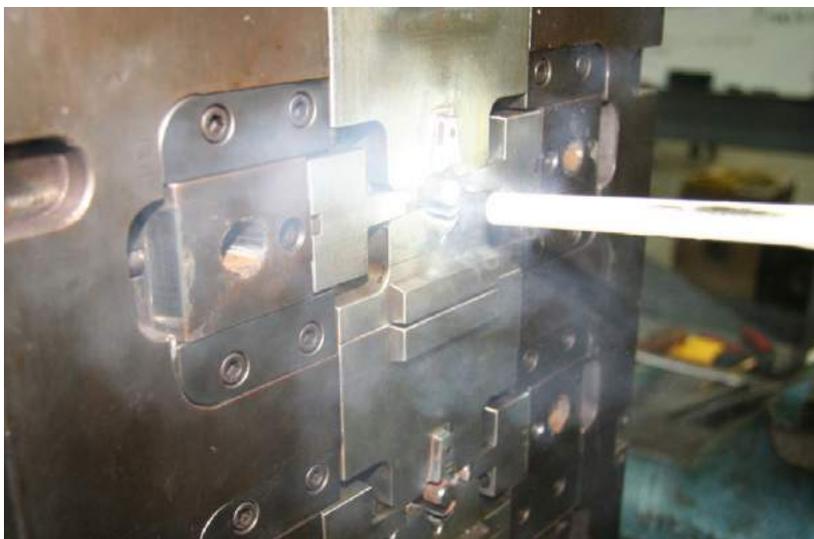


Fig. 7 Left: Dry ice cleaning of cavity and vent. Top right: before cleaning. Bottom right: after cleaning

not react with anything – there is no chemical change on the substrate being cleaned. CO<sub>2</sub> is an inert and non-toxic molecule and will not cause tooling to oxidise. In fact, CO<sub>2</sub>, being 40% heavier than air, displaces oxygen.

Cleaning with dry ice may also improve a manufacturer's Overall Equipment Effectiveness (OEE) score. It simply produces a better clean. Dry ice has a low coefficient of friction, making it a good media for getting into tight, complex geometries which are otherwise difficult to clean. Many cleaning solvents leave a chemical residue behind which can cause scrapping of the next few shots.

### Quality, environmental and cost considerations

#### Common moulding problems

One of the challenges that injection moulders face is mould fouling or soiling because of the off-gassing of the various binders utilised in Powder Injection Moulding. When cavities become fouled and/or vents get clogged, a large number of moulding problems can arise. Table 1 notes some of the common problems that can occur, according to *Sun Micro-Systems' Cosmetic & Structural Defects Manual* and FIMMTECH's *Standardizing Validations, Common Defects in Injection Moulding*.

It is inevitable that vents will clog and cavities will get dirty, and it is all too common that an operator will walk up to a supervisor with a part that has a minor blemish and ask if the part is OK to use. The answer is predictably no. Why does this happen? Because mould cleaning is often postponed and not celebrated. It is a job that nobody wants. Why not take mould cleaning from a reactive, fire-fighting drill, to one that is managed?

#### Environmental impact

A further reason why the injection moulding industry is changing to dry ice cleaning is worker safety and a better environment. A major consideration for any cleaning application



Fig. 8 A portable dry ice cleaning machine

Problem	Possible cause
Short shot	Clogged vent
Flash	Clogged vent
Burns	Clogged vent
Mould damage	Clogged vent
Plate-out	Dirty mould cavity
Contamination	Dirty mould cavity
Splay	Dirty mould cavity
Weld lines	Clogged vent

Table 1 Common moulding problems can often be triggered by clogged vents and dirty mould cavities

Option	Annualised cost
<b>Hexane aerosol cleaning</b>	<b>\$56,174</b>
Acetone/Glycol Ether cleaning (five gallon pails)	\$22,914
Acetone/Glycol Ether cleaning (drums)	\$11,454
Acetone/PCBTF cleaning (five gallon pails)	\$34,681
Acetone/PCBTF cleaning (drums)	\$26,020
Dry ice blasting (no system purchase, same labour)	\$3,546
Dry ice blasting (no system purchase, double labour hours)	\$7,113
<b>Dry ice blasting (system purchase, same labour)</b>	<b>\$6,198</b>
Dry ice blasting (system purchase, double labour hours)	\$10,680

Table 2 Cleaning media cost comparisons

should be the impact that it has on the environment, as well as any risks to workers. Many cleaners contain Volatile Organic Compounds (VOCs) that are harmful not only to people, but also the environment.

In an independent study conducted by Katy Wolf on behalf of the United States Environmental Protection Agency (EPA) a company was under scrutiny for its use of cleaning solvents that could endanger personnel. Dry ice cleaning was introduced as an alternative method for cleaning. Not only did the dry ice cleaning process prove to be better and faster, but it highlights another reason why injection moulders are switching to dry ice cleaning – to save money. During the study, the company pulled records of its annual purchases of the aerosol cleaning cans. It also calculated the annualised cost of purchasing dry ice and amortising the dry ice cleaning equipment (Table 2).

**Cost reduction**

This leads into the final reason why injection moulders are changing over to dry ice cleaning. Not only did the previously cited study achieve greater worker safety and a healthier work environment, but costs were lowered – both in terms of cleaning materials and labour.

Dry ice blasting also offers the chance to increase productivity. The dry ice cleaning process is four-to-six times faster, which not only increases production rates, but also lowers cleaning labour costs. A common problem in manual cleaning of metal moulds is that it is very labour intensive. For those tracking OEE Scores, this equates into an availability loss.

**Conclusion**

We are always searching for ways to do things better, faster and at lower costs. Cleaning with dry ice has successfully helped numerous

Powder Injection Moulding companies fulfil their various plant initiatives for quality, productivity, the environment and cost reduction. Dry ice cleaning has brought meaningful innovation to many companies by encouraging them to embrace maintenance and cleaning as a critical business function. We believe that the nature and culture of cleaning moulds in the PIM industry will never be the same.

Depending on the part, some PIM producers are also cleaning moulded parts prior to debinding and sintering. The technology is, however, primarily being used for mould cleaning.

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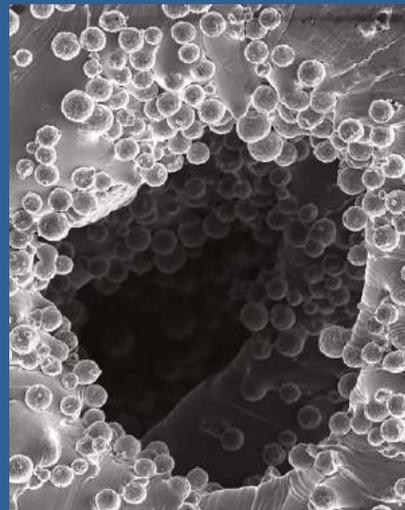
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