

FOR THE MIM, CIM AND SINTER-BASED AM INDUSTRIES

Vol. 14 No. 2 JUNE 2020

POWDER INJECTION MOULDING INTERNATIONAL



in this issue

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Publisher & Editorial Offices

Inovar Communications Ltd
11 Park Plaza
Battlefield Enterprise Park
Shrewsbury SY1 3AF
United Kingdom
Tel: +44 (0)1743 211991
Fax: +44 (0)1743 469909
www.pim-international.com

Managing Director & Editor

Nick Williams
nick@inovar-communications.com

Publishing Director

Paul Whittaker
paul@inovar-communications.com

Deputy Editor

Emily-Jo Hopson-VandenBos
emily-jo@inovar-communications.com

Assistant Editor

Kim Hayes
kim@inovar-communications.com

Consulting Editors

Prof Randall M German
Former Professor of Mechanical Engineering,
San Diego State University, USA
Dr Yoshiyuki Kato
Kato Professional Engineer Office, Yokohama, Japan
Professor Dr Frank Petzoldt
Deputy Director, Fraunhofer IFAM, Bremen,
Germany
Dr David Whittaker
DWA Consulting, Wolverhampton, UK
Bernard Williams
Consultant, Shrewsbury, UK

Production Manager

Hugo Ribeiro
hugo@inovar-communications.com

Advertising

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

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For the MIM, CIM and sinter-based AM industries

Accelerating innovation and diversification

As companies around the world reel from the impact of coronavirus (COVID-19), it appears that the Metal Injection Moulding, Ceramic Injection Moulding and sinter-based Additive Manufacturing specialists covered by *PIM International* may not be quite as devastatingly hit as those in other industries.

The main reason for this is the wide diversity of markets that these technologies serve, combined with the fact that they are extremely competitive versus manufacturing processes such as investment casting and machining.

This does not mean to say that the industries we cover will be spared the impact of the crisis entirely, but it may perhaps give those involved a greater chance to position themselves for the potentially very different manufacturing landscape that lies ahead. For MIM and CIM producers, perhaps this is a chance to seize the initiative and press ahead with R&D to unlock new business opportunities available through the adoption of AM.

This issue of *PIM International* offers a range of perspectives on how PIM producers are embracing the opportunities afforded by AM. German MIM specialist Element 22 is leveraging its debinding and sintering expertise to move into the AM market (page 57), whilst CIM specialist Formatec shows how components can be designed for both PIM and ceramic AM, giving the customer much more freedom with regards to production strategies (page 77). In another interesting overlap of ceramic AM and MIM, CMG Technologies explores ceramic AM for custom setters in its MIM production (page 101).

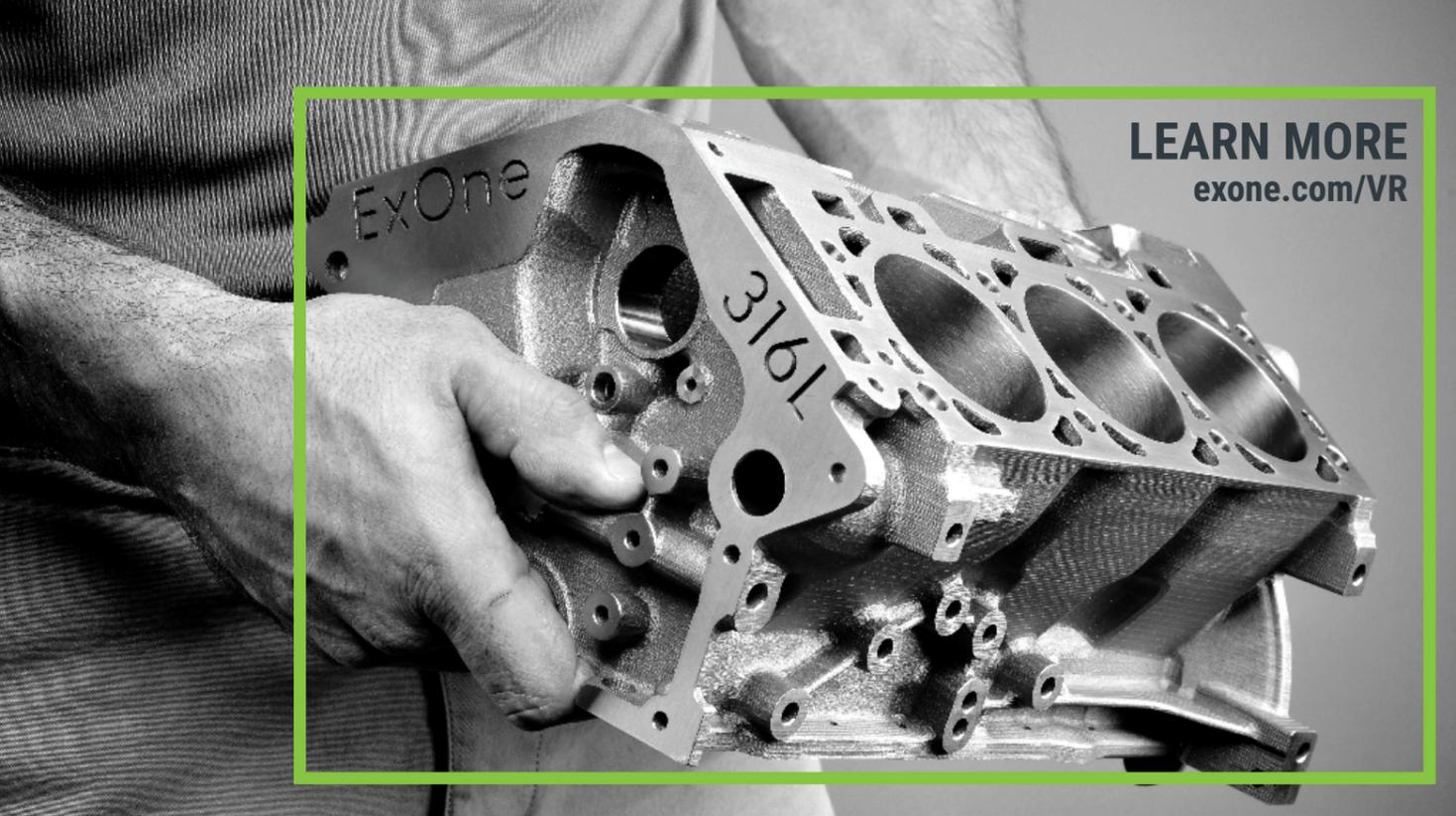
At the end of the day, such innovation could lead to cost reductions, new opportunities and the ability to offer customers a far broader range of production volumes, from one to one thousand to one million and beyond.

Nick Williams,
Managing Director & Editor



Cover image

Metal injection moulded cpTi screw with M2 thread used in implant applications
(Courtesy Element 22)

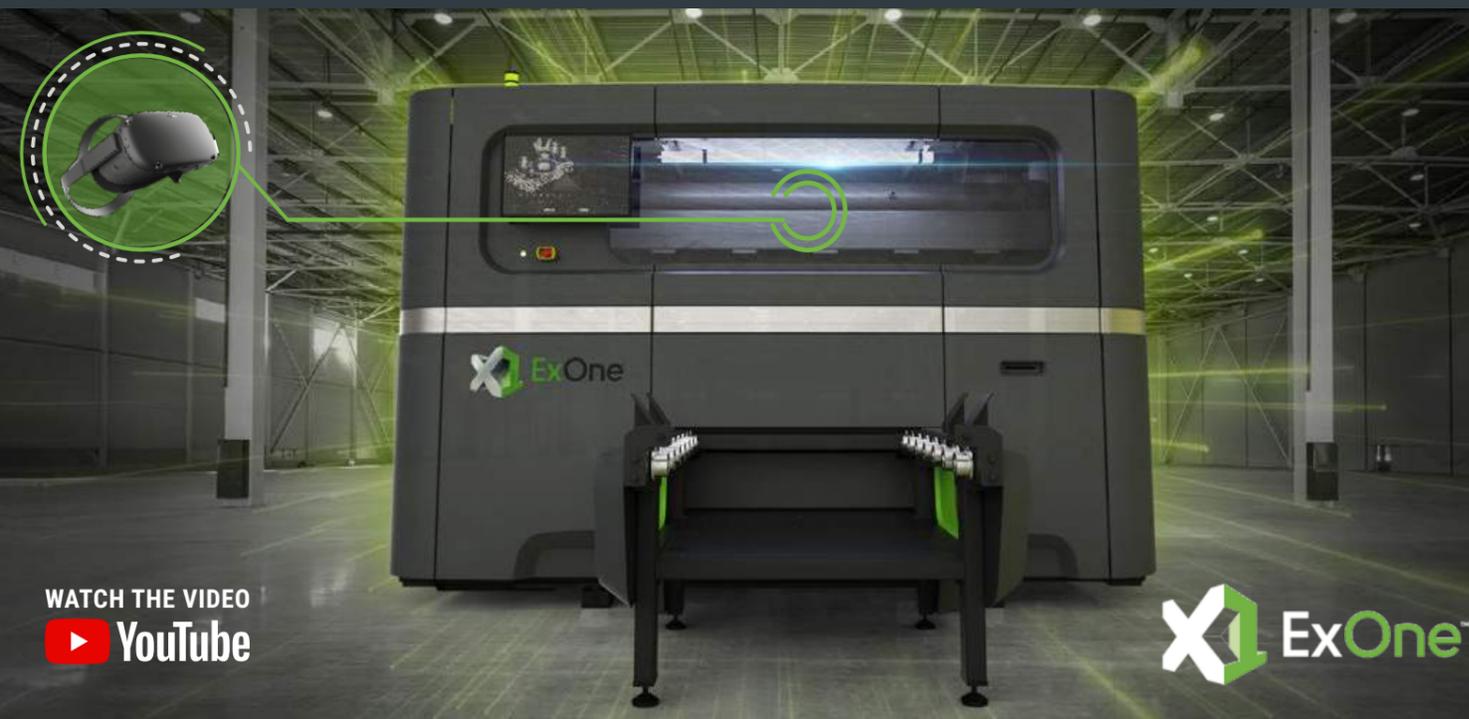


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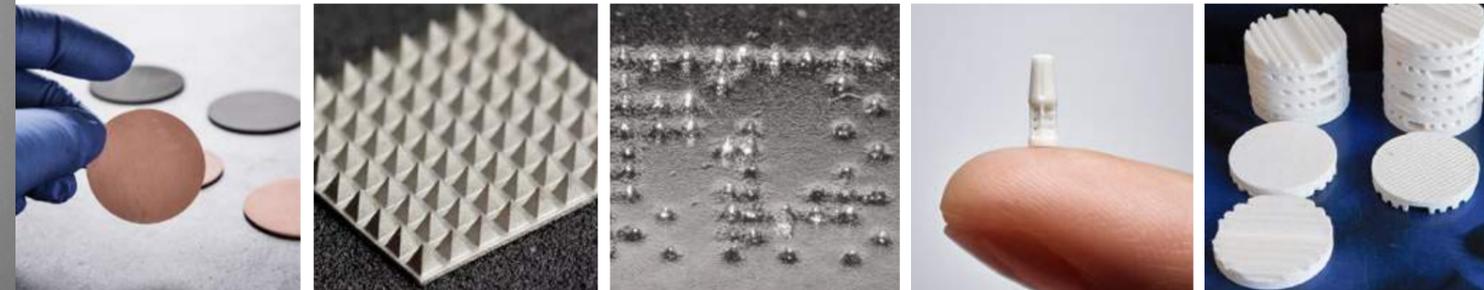


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In this issue

57 Element 22: A leader in titanium MIM leverages its expertise to advance sinter-based Ti Additive Manufacturing

The production of titanium components by powder-based processes requires specialist knowledge and in-depth expertise in the handling and, in particular, the debinding and sintering of this highly reactive metal. Element 22 GmbH is a global leader in the Metal Injection Moulding of titanium and its alloys, and a growing focus of the company's development activities is sinter-based Additive Manufacturing. Dr Georg Schlieper visited the company on behalf of *PIM International* and reports on the current state of production and the company's future ambitions.

69 Digitising part production: A new approach to creating unique part IDs for MIM components

Terms such as Industry 4.0 and the Digital Twin trace back to the growing trend to digitise industrial processes. Modern production equipment delivers a huge quantity of process data, and the continuous analysis and correlation of these data could result in process stability improvements. For such advances to be applied to MIM, the permanent surface marking of each part with a unique ID is required. Prof Dr-Ing Frank Petzoldt and Lutz Kramer, Fraunhofer IFAM, Bremen, Germany, report on the development of a cost-effective solution to what currently poses a significant technical challenge.

77 Making the business case: How sinter-based Additive Manufacturing can compete with PIM

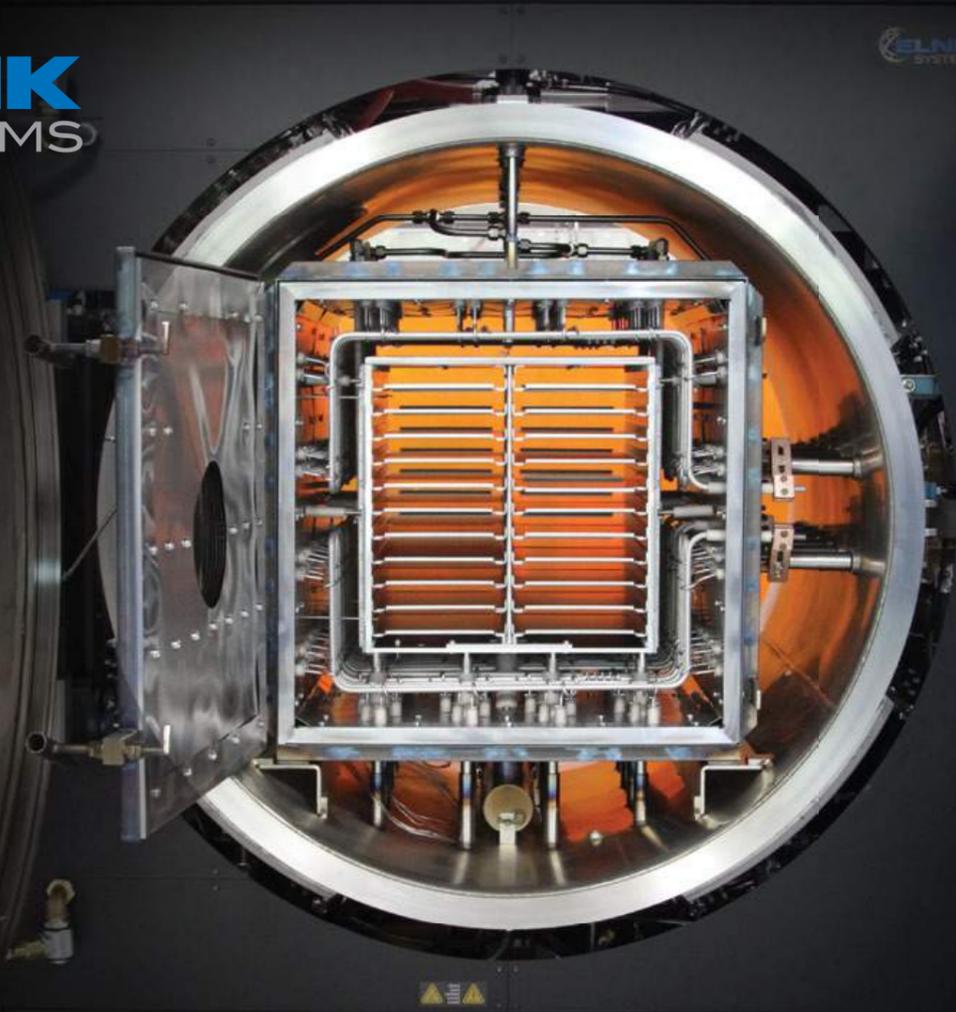
When it comes to closely related manufacturing processes such as PIM and sinter-based Additive Manufacturing, the ability to design a part that could be produced by either process has numerous advantages. Loran Mak, from AM machine developer Admatec Europe, and Harrie Sneijders, from sister company and PIM specialist Formatec Technical Ceramics B.V., present an overview of Vat Photopolymerisation (VPP) and PIM technologies and, through two case studies, highlight how the advantages of the processes can be leveraged when making the business case for each application.

87 Reducing MIM part costs with more expensive materials? The re-evaluation of a major 3C application

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Industry News

The impact of COVID-19 on the global Metal Injection Moulding industry

The coronavirus (COVID-19) pandemic has had an unprecedented impact on the global economy, with few sectors left unscathed. When looking to understand the impact on MIM, the industry's long-established regional market variations, combined with the sheer breadth of its end-use applications, appear to have prevented the downturn in from being as severe as witnessed in other industries whose fortunes are solely tied to, for example, the automotive sector.

The following report is based on communications with a number of industry professionals globally. Whilst this should be considered as no more than 'taking the mood' of the MIM industry, it gives some insight into the impact of the crisis as of mid-May.

Asia

The crisis has had a major impact on the Chinese economy, and China's MIM industry is no exception. Feedback from China is mixed; however, the current and anticipated drop in global consumer spending is a far greater concern than the limited impact of the temporary shutdown. Whilst there was some disruption to production as a result of temporary closures, it is understood that the necessary production capacity is now available.

MIM components for smartphones remain the dominant market for the industry in China and it was stated that the release of Apple's second generation iPhone SE earlier this year was a huge help to many MIM producers as, whilst this was an updated model, it used many existing parts that did not require complex approval processes. It was also suggested that whilst project planning and designs for a new generation of smartphones were completed in early 2020, production plans were delayed by "about a quarter" and are now being resumed.

The biggest concern for this application area is shrinking consumer spending. Factory shutdowns have led to a decline in personal income, leading to an unwillingness to spend on consumer electronics, the main business area for most of China's MIM companies. Adding to this has been the closure of retail outlets for

consumer electronics in many countries, all of which has led to a drop in MIM part purchase orders.

This drop in purchase orders was also seen in non-3C MIM parts, where some orders were cancelled or postponed because of end-user factory closures. At the very best, it is hoped that the crisis will be limited to a 'lost quarter' of production. Additionally, a further effect of the crisis has been the moving of production by some international buyers to spread supply chain risk. It was stated by one source that Taiwan has seen increasing orders for MIM parts as a result.

In Japan, most MIM companies and metal powder producers have been able to maintain their production during the crisis. This production is, however, based on orders placed before the current disruption. As a result, for many companies, production will continue at a relatively high level until August. The crunch point is



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expected to be September, assuming the number of new purchase orders keeps dropping.

It was stated that all companies are able to transition to full production at any time, but the recovery of the market is, of course, beyond their control. With the Japanese economy being so deeply connected to the world economy, global challenges will continue to directly impact Japanese MIM producers. In terms of specific markets, production of components for smartphones was reported to have dropped significantly, but the automotive market was shrinking by a slower rate.

With regards to MIM powder production, global supply challenges have led to short term opportunities, including, it was stated, an increased demand for Japanese powder in Taiwan because of issues relating to the purchase of Chinese powder. As with Japan's MIM parts producers, all eyes are on September and the volume of purchase orders that will be received.

Some companies are reported to be seizing the opportunity presented by this period to progress R&D activities and investigate new technologies such as Additive Manufacturing. "It is the business strategy of each company whether to regard this difficult period as an opportunity or as a matter of course. It is a critical time when the skill of each company's management is tested," stated one source.

Europe

Europe's MIM industry is, thanks to the technology's early adoption by major European PM producers, famed for its success in the automotive sector. This has meant that many in the European MIM community have been hit by the present situation in the automotive sector.

One producer stated that its MIM facility had to halt production for a period and, now that it has restarted, it is operating at 50% of capacity and using short time working hours. Looking ahead, the firm estimated that production would be 30% down over the next three or so months and, in the longer term, down 15-20%.

The picture varies across the continent, however, and another large MIM producer stated that it was running at 100% capacity and had only stopped production for ten days, with this being made up for by working through Easter and week-ends with the agreement of workers. In terms of markets, firearms was reported as the most robust. Looking ahead, this company believes that a reduction in sales and production in the next months of 20-30% can be anticipated, subject to the start of a hoped-for recovery in September.

Just as there is no good news around automotive, two other important sectors for Europe's MIM producers, aerospace and luxury goods, are also reported to have been severely hit. Firms that focus on these markets anticipate a drop in production of greater than 50%. "This time, the s*** has really hit the fan..." commented one producer.

North America

Just as MIM in Europe has automotive as a leading end-use market, so North America has firearms, and in such a time of crisis, firearms sales are a major driver of the domestic MIM industry. In relation to COVID-19, it was suggested that strong firearms sales are not solely driven by a desire for self-defence or 'doomsday planning', but also by increased hunting for food and recreation. Outside of COVID-19, in an election year the fear of new firearms legislation always drives up sales. This is reflected in the currently high stock prices of firms such as Sturm, Ruger & Company, Inc, and Smith & Wesson.

Other important US markets for MIM are medical and dental. The market for the latter, where MIM is used extensively for orthodontic brackets, has "fallen off a cliff", stated one source, because people simply aren't choosing to visit the dentist or orthodontist. The production of MIM surgical devices is mixed, but potentially trending down slightly. Other markets are reported as mixed, but falling slightly due to prevalent uncertainty.

On the materials supply side, one leading supplier stated that a flow of purchase orders is still coming in but noted that, "powder deliveries/lead time have moved out substantially."

With regards to capital expenditure, one leading equipment supplier noted that, whilst it is unaware of any MIM company shutdowns, there are now some delays in facility expansions or upgrades because of regulations around building construction work.

As with other regions, the biggest challenges are anticipated in the third and fourth quarters of 2020, when some contracts have closed out and new business contracts failed to materialise during the first half of the year.

Final thoughts

As one leading global MIM firm stated, the MIM industry will follow the fate of the market segment it caters to – but, depending on how quickly the COVID-19 situation is brought under control, "the main markets could bounce back within the next eight-to-sixteen months". This firm reported that, whilst it had been forced to reduce manpower in its facilities in order to ensure social distancing, none of its global customers had been inconvenienced.

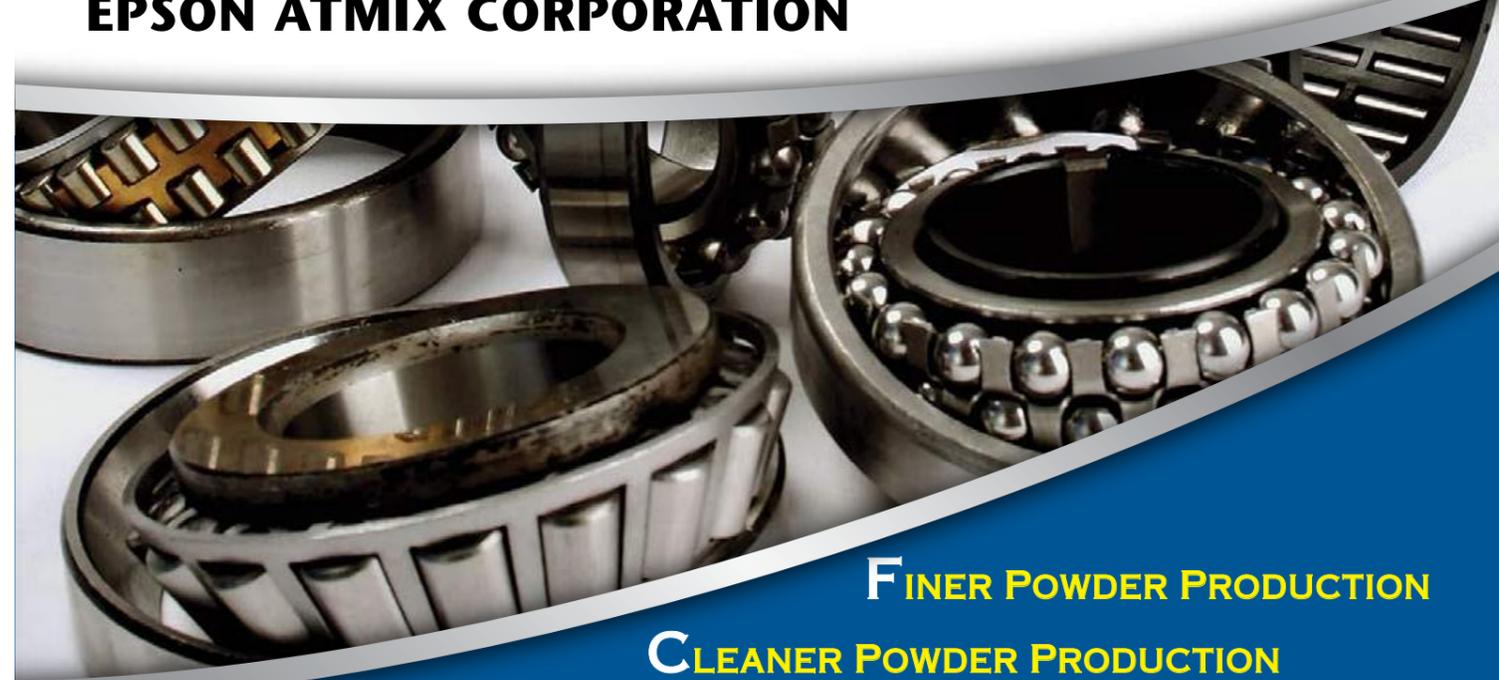
On this point, it should be considered that highly-automated MIM facilities, making components that require little by way of manual finishing operations, will inevitably have an easier path through this crisis than firms where extensive manual finishing procedures are needed. In the MIM industry, such production exists at both extremes of the component value spectrum, be they smartphone buttons or luxury watch cases.

Finally, will the current geo-political situation have an impact on MIM? There is evidence of companies reconsidering their global supply chain strategies and the associated risks. Whether this will have a profound effect on the MIM industry remains to be seen. ■

Thanks to all those who contributed their insight for this news report.

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JAPAN

Mr. Ryo Numasawa
Numasawa.Ryo@exc.epson.co.jp

ASIA and OCEANIA

Ms. Jenny Wong
jenny-w@pacificsowa.co.jp

CHINA

Mr. Hideki Kobayashi
kobayashi-h@pacificsowa.co.jp

U.S.A and SOUTH AMERICA

Mr. Tom Pelletiers
tpelletiers@scmmetals.com

EU

Dr. Dieter Pyraseh
Dieter.Pyrasch@thyssenkrupp.com

KOREA

Mr. John Yun
dkico@hanafos.com

Strong year recorded for China's MIM industry in 2019, with smartphone production continuing to drive growth

A survey conducted by the Metal Injection Moulding Committee of the China Powder Metallurgy Alliance (CPMA) has revealed that the MIM industry in China continued on a rapid growth track in 2019. The total sales volume of MIM parts in China (excluding Taiwan), was estimated to be RMB 6.7 billion, up by 17.5% on 2018. These sales were primarily driven by the 3C sector. In addition, smart wearable devices, micro-gearboxes, hardware and automotive parts contributed to growth.

There are currently over two hundred MIM firms operating in China, among which two companies report sales above RMB 1 billion. Ten companies are reported to have achieved sales of more than RMB 100 million.

Components for smartphone applications continued to dominate the market, with modest growth reported, whilst the demand for components for smart wearable devices continued to grow. There was, however, a drop in the market share for parts for computers and medical devices. Application areas, by sales value, are shown in Fig. 1.

In 2019, the total volume of MIM powder sales recorded was approximately 10,000 tons, 15–20% higher than that reported in 2018. There is recognition, however, that MIM grade powders are now also being sold to the growing Additive Manufacturing industry, potentially affecting these figures. With regards to MIM feedstock production, the survey found that the market share of

domestic Chinese feedstock brands has risen to around 65% of the entire market. Of the international producers, BASF SE's Catamold catalytic debinding feedstock continues to dominate.

Stainless steels continue to dominate production, accounting for 70% of the market by weight. Low-alloy steels account for 21%; cobalt-based alloys 6%, and tungsten-based alloys 2%. The balance includes titanium, copper and cemented carbides, to name a few.

Outlook

The CPMA states that, driven by the efforts and technological progress of China's MIM industry, the overall awareness of MIM in China is steadily improving.

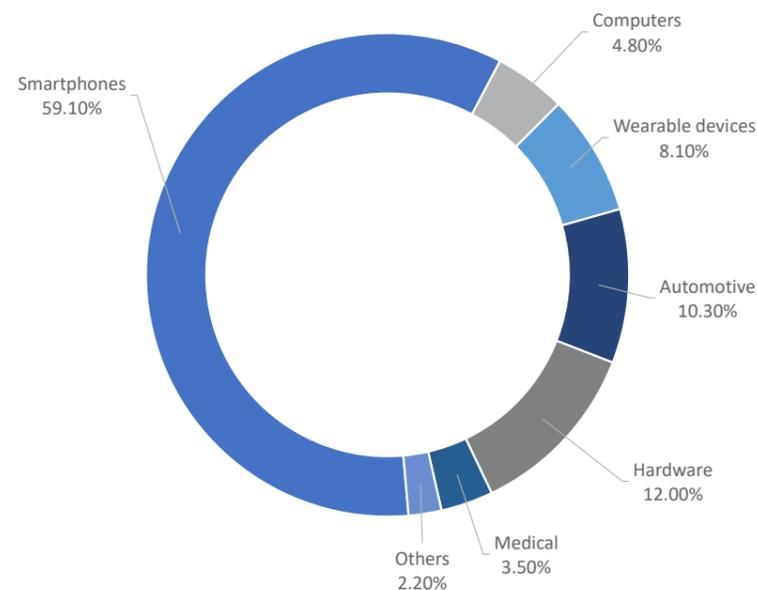
In terms of material performance, dimensional tolerances, production efficiency and manufacturing costs, as well as labour protection and environmental impact, MIM is achieving a comprehensive competitive advantage over the investment casting and CNC machining industries. As a result, MIM is expected to be used for new applications in the automotive sector, for both conventional and electrified vehicles.

In the 3C sector, new folding screen devices, including both smartphones and tablets, will appear in the market during 2020 and the industry estimates that folding screen penetration will reach 5% of the market. More broadly, smartphone manufacturers will increase their use of MIM products, bringing new growth opportunities.

The survey's authors concluded that, propelled by 5G technology and the progress of IoT (the Internet of Things), MIM products will continue to embrace a wide range of new opportunities. Moreover, it was stated that the introduction of metal Additive Manufacturing is likely to give a further boost to the industry.

www.cpma.com.cn ■

Chinese MIM application areas based on sales, 2019



Chinese MIM application areas based on sales, 2019. Data courtesy of the MIM Committee of the China Powder Metallurgy Alliance (Courtesy CPMA)

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Yahao Materials & Technology to expand MIM-grade powder production

With the rapid growth of the Metal Injection Moulding industry on the back of the demand for smartphone and other high-volume 3C applications, there has been a significant increase in the demand for MIM-grade stainless steel and soft magnetic powders. In addition, demand is increasing from sectors such as the automotive industry as well as for application in metal Additive Manufacturing processes such as Binder Jetting. While future opportunities look promising, demanding new applications can pose technical challenges.

To keep pace with anticipated market growth, Yahao Materials & Technology Co. Ltd., based in Hebei Province, China, reports that in May 2019 it started the construction of its second metal powder plant.

This 33,000 m² plant is expected to contain twelve high-pressure gas-water atomisation systems and three vacuum gas atomisation systems, with operations starting in August 2020.

The facility is expected to produce 8,000 tons of powder per year, accounting for RMB 240 million output value. Supporting this development is a strong commitment to R&D, and the new facility will feature laboratories for chemical analysis, SEM microscopy, metallographic analysis, mechanical testing and magnetic properties.

Yahao Materials & Technology Co. Ltd. told *PIM International* that over the past twelve years it has achieved considerable success, but stressed that there is also an ongoing awareness of the need



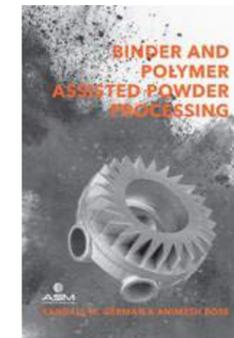
A digital render of the new facility, currently under construction (Courtesy Yahao Materials & Technology Co. Ltd)

for process innovation, new product development and overcoming technical barriers, which will help the company to maintain its competitiveness in the industry.

www.yahaochina.com ■

ASM International publishes new book on binder and polymer assisted powder processing

ASM International has published a new book, *Binder and Polymer Assisted Powder Processing*, co-authored by Randall M German and Animesh Bose. The 273-page book focuses on the basic principles and options available for the application of polymers and natural organics to powder processing. It links materials, powder characteristics, forming processes and product attributes together to give what the authors believe to be the first unified treatment on polymer-assisted powder processing.



Randall M German and Animesh Bose's new book on Binder and Polymer Assisted Powder Processing has been published by ASM International (Courtesy ASM International)

The processes discussed include injection moulding, sinter-based Additive Manufacturing, uniaxial die compaction, tape casting, extrusion, slip casting and slurry casting. In each process, the technical requirements are outlined and polymer candidates identified.

ASM International explains that the book bridges the practical aspects of cost, availability and safety with fundamental structure, properties, processing and tests. Each chapter concludes with a review of current industrial standards and examples of practices.

The book covers the following topics as dedicated chapters:

- Engineering powders
- Binder constituents
- Binder formulation
- Powder-binder feedstock mixing and testing
- Shaping processes
- Binder removal
- Sintering densification
- Component mechanical properties
- Case studies of powder-binding processing practices
- Opportunities for powder-binder forming technologies

The book is available to purchase via ASM International's website.

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Melrose estimates 20% drop in sales, announces return to productivity

On May 7, Melrose Industries PLC, UK, parent company of GKN Group, released a trading update for the four months from January 1, 2020, to April 30, 2020, and reported an estimated 20% sales decrease due to the impacts of the coronavirus (COVID-19).

The group stated that it had traded in line with expectations from January 1, 2020, until mid-March 2020, at which point the global impact from COVID-19 caused significant disruption, resulting in many factories being shut or remaining only partially open. As a result, the group's sales for this period were down approximately 20% compared to the same period last year.

The group's Automotive and Powder Metallurgy businesses have reportedly seen similar trading patterns to each other, with their

factories in Europe and North America largely being shut since mid-March. Factories closed in whole or part during this period represented approximately 88% of the 2019 sales. All the group's factories in China have now been open for several weeks and are seeing encouraging signs of a recovery in demand. There is also a steady process of factories being reopened in Europe and North America, albeit a gradual return with productivity affected by social distancing measures.

The group explains that management has taken significant actions to reduce the cost base of these businesses, and plans are being drawn up to position for the future. In both cases, these businesses enjoy large market shares and strong customer relationships, and the board believes significant opportunity

exists to improve their performance. The net result of the above trading conditions in the period was that these two divisions combined had a sales decline of 31% compared to the same period last year.

Simon Peckham, CEO of Melrose Industries PLC, commented, "Our divisional management teams and head office employees have responded brilliantly to these unparalleled circumstances, which are likely to remain challenging for a while. During the next few months we will put in place plans to position our businesses to achieve their future potential in different market conditions. Melrose has a track record of managing its businesses successfully in all market environments and crucially our recent cash generation performance shows we have been able to maintain the strength of the balance sheet to position the group's businesses in the best way for the future."

www.melroseplc.net ■

Severstal completes acquisition of carbonyl iron powder producer Sintez

PAO Severstal, a leading steel and steel-related mining company headquartered in Moscow, Russia, has acquired 100% of the shares of Sintez-CIP Ltd and Sintez PP Ltd, the owners of the only producer and supplier of carbonyl iron powders in Russia and the CIS region. Sintez-CIP will become part of Severstal's metalware manufacture division, under the operational management of Sergey Kovryakov, CEO of Severstal-metiz.

Sintez-CIP produces a wide range of unique carbonyl iron powders for firms around the world. Carbonyl iron powder is used in MIM and other PM-based technologies. It is also widely used in electronics, primarily in the automotive industry (electronics in cars, electric vehicles), as well as in the manufacture of household appliances, mobile phones, computers, and televisions.

Sintez-CIP is reported to be the second-largest producer of these products globally, holding approximately 10% of the market share. The company produced more than 1,500 tons of finished goods last year, and exported more than 95% of its sales.

Alexander Shevelev, CEO of Severstal, commented on the acquisition, "This investment reflects our focus on two of Severstal's strategic priorities – 'New Opportunities' and 'Excellent Customer Experience'. Through the implementation of breakthrough technologies, we are bringing unique solutions to the market in order to satisfy the needs of modern customers, as well as, in some cases, anticipating their future demands."

"Integrating Sintez-CIP into Severstal will add a new trajectory of development for the company into promising markets such as electronics, where we expect sustained growth through key developments," he continued. "Examples include the electrification of transport, the development of telecommunications infrastructure, mobile electronics, and finally 'Binder Jetting', which is considered to be an important technological breakthrough due to its high processing speed and low costs."

Andrey Laptev, Director of Business Development and Corporate Venture Projects at Severstal, added, "Sintez-CIP has unique competencies that have enabled it to occupy 10% of the fast-growing global carbonyl iron market, and continually increase its presence in the most promising segments of the sector."

"We are aiming for consistent growth in this high-margin market, using the broad competencies and market opportunities Severstal has cultivated," he explained. "Our overarching goal is to create a world-class Powder Metallurgy centre of excellence within the business. Sintez-CIP allows us to expand our market influence, and also creates a springboard for us to enter international markets."

www.severstal.com | <https://en.sintez-cip.ru> ■



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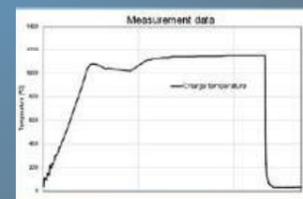
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Formnext 2020 remains on course for November, with digital options if required

Mesago Messe Frankfurt GmbH, the organiser of Formnext, reports that it still expects the event, scheduled to take place in Frankfurt, Germany, from November 10–13, 2020, to go ahead. It also states that it is working on a concept for safeguarding the health of attendees and a supplementary digital programme.

"Additive Manufacturing has made a significant contribution to the fight against the corona pandemic in recent months and is still a driving factor for innovation, resource-efficient production, and the technological management of future challenges," stated Sascha F Wenzler, Vice President Formnext, Mesago Messe Frankfurt GmbH. "It is all the more important that with Formnext 2020, we continue to support and advance this trend even in these economically challenging times."

According to the organiser, the rulings of the Federal Government and the Federal States of Germany, dated May 6, 2020, stating that trade shows no longer fall under the category of major events that pose a particular health risk, give cause for optimism that the event can run as planned in November.

Wenzler added, "This is great news not only for the trade show industry, but for the entire economy. Trade shows are an important driver of innovation and value creation in industry, especially after months of economic standstill in many industries and sectors."

The organiser explained that the health of exhibitors, visitors and employees remains a top priority. Therefore, concepts are currently being developed to ensure the highest standards of health protection. These concepts centre on a range of measures focused on hygiene (for example, higher cleaning frequency), social distancing (including professional crowd management), and a generous supply of fresh air (including a regular exchange of the hall air every hour). A thorough registration process for visitors is also planned, as well as tickets that are only valid on specific days. A fully electronic registration and payment system is expected to allow unnecessary contact to be avoided. A self-declaration concerning attendees' current state of health will be mandatory.

Formnext's organisers are also taking new approaches in the design of the exhibition space and booths. The aisles between the booths will be significantly wider (increasing from 3 to 6 m) and will be flanked by a 1 m-wide communication strip on each side. There will also be CCTV and trained personnel in the hall to monitor whether the social distancing requirements are being observed. The general distance concept is said to be based on a calculation designed to ensure a sufficiently large exhibition space per visitor. Booth construction guidelines are also being adapted accordingly, and recommendations regarding catering, for instance, will also be provided.

These concepts are currently being coordinated with the responsible authorities and will be implemented in due course. In addition to health protection, Formnext 2020 is reportedly being designed in consideration of a number of other important factors, such as the wider economic environment, the economic situation in the AM sector, and developments in the European and global travel industry. "Ultimately, even in these challenging times, we want to organise a trade show that is as responsive as possible to the current situation and the needs of participants and the market," stated Wenzler.

Digital options for Formnext

"We remain convinced of the unique value and advantages of a physical exhibition," explained Wenzler. "And although digital interaction will never be able to replace face-to-face contact, it does offer more scope than previously thought possible only a few weeks ago." It is for this reason that the organiser intends to consider digital options for Formnext. For example, exhibitors will also be given the opportunity to present products and solutions digitally to the international trade audience.

Concepts and platforms are currently being developed, with further details to be released in the coming weeks. www.formnext.com ■



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DSH adds 'block time' process metallurgy support for MIM and sinter-based AM

DSH Technologies, a sister company of Elnik Systems, LLC, headquartered in Cedar Grove, New Jersey, USA, plans to introduce 'block time' process metallurgy support to its service offerings. The new service will offer companies in the metal part making industry access to the team at DSH, which includes a Chief Process Metallurgist, in ten, twenty or forty-hour blocks of paid support time.

"Not every company has the opportunity to hire or bring onboard personnel with years of history in processing metal parts. This is a challenging industry. For years the team at DSH has been helping companies develop new parts and overcome challenges with existing parts. Our goal is to make it easy for companies to access process metallurgy expertise, without having to worry about the onboarding and hiring processes," explained Stefan Joens, the company's Vice President.

"With our current team here, Bryan Sherman [Chief Metallurgist/Project Manager], Bruce Dionne [Vice President of Operations, Elnik] and myself, we can draw on decades of processing experience and offer a lot of help to companies in all areas of metal part making, from incoming material specifications through final part delivery."

Block support time will be paid in advance, after which point the DSH team will log all calls and provide support remotely and/or virtually throughout the time purchased. Focused around, but not limited to, the Metal Injection Moulding and sinter-based AM industries, a wide range of support will be provided, ranging from metallographic analysis and processing problems to setter design and facility planning.

DSH also has multiple pieces of equipment in house to perform debinding, sintering and some metallography work should that level of support be needed as well.

www.dshtech.com



Industrial-grade Elnik Systems sintering furnaces at DSH (Courtesy DSH Technologies)

Sandvik achieves AS9100D aerospace certification for titanium and nickel-base superalloy powders

Sandvik AB, headquartered in Stockholm, Sweden, reports that its new powder plant for titanium and nickel-base superalloys has received AS9100 Revision D certification for deliveries to the aerospace industry.

The powder plant for Osprey® titanium and nickel-base superalloys was officially opened at the end of 2019 in Sandviken, Sweden. Since then, extensive work has been ongoing to ramp up the highly automated plant, fine-tuning all processes and qualifying the powder to ensure the best possible consistency, morphology and quality. The first two titanium powders produced at the plant are Osprey Ti-6Al-4V Grade 5 and

Osprey Ti-6Al-4V Grade 23. The nickel-base superalloys are Osprey Alloy 625 and Osprey Alloy 718.

"Having atomised fine metal powders for more than forty years, and supplying titanium to the aerospace industry since the 1980s, Sandvik is no stranger to powder atomisation or the requirements of the most demanding industries," stated Keith Murray, Vice President of Global Sales, Sandvik Additive Manufacturing.

"Now we are one of few companies that has the new and prestigious AS 9100D quality certification for our Osprey titanium powder and nickel-base superalloys used for Additive Manufacturing. It is a true milestone, which will facilitate many customer

collaborations going forward." In addition to a shift towards sustainable manufacturing, Sandvik explains that traceability is of vital importance in the aerospace industry, the company can offer traceability for its titanium powder, which is made possible by having the full supply chain inhouse – from titanium sponge to finished powder.

The new titanium powder process uses advanced electrode inert gas atomisation technology to produce highly consistent and repeatable titanium powder with low oxygen and nitrogen levels. The automated production process is also supported by several industrial robots and a dedicated downstream sieving, blending and packing facility.

"Our highly automated manufacturing process ensures excellent consistency – and the powders demonstrate optimal particle size distribution," Murray concluded.

www.additive.sandvik



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Ceramic AM research project aims to make production of complex vaccines faster and cheaper

Lithoz GmbH, Vienna, Austria, has initiated a research project called Nessie, along with SINTEF, a research organisation located in Oslo, Norway, and IBET, a biopharmaceutical research centre based in Lisbon, Portugal, to produce complex vaccines in large quantities at low cost using ceramic Additive Manufacturing. Along with Lithoz, SINTEF, and iBET, Genlabet and Cerpotech have also joined the project, bringing with them their expertise on the manufacturing of biopharmaceuticals and innovative materials, respectively.

The project partners explain that the COVID-19 pandemic highlights the importance of and the great need for vaccines that can effectively combat such diseases. However, the development of an effective vaccine involves much effort and the highest safety standards, which means production is often slow and very expensive. Nessie addresses these weaknesses specifically and aims to increase the efficiency with which vaccines are produced. It is already contributing



The Nessie project has used Lithoz's ultra-high-resolution ceramic AM to produce novel chromatographic columns, a first-of-its-kind hybrid structured absorbent with tailored shapes and controlled porosity (Courtesy Lithoz GmbH)

to the development of novel methods to purify viruses, such as adenovirus.

According to the project partners, adenoviruses are excellent vectors for delivering genes or vaccine antigens to humans, with many of the successful vaccines actually using viruses to deliver the necessary elements to become immune. However, such viruses are expensive to produce and like many substances intended for clinical use in humans, extra caution must be taken with regards to the purity and purification of these viruses. By using ultra-high-resolution ceramic Additive Manufacturing and applying a novel design for the production of chromatographic columns (the most advanced purification technology), the Nessie project will improve separation and reduce production costs. Nessie has reportedly succeeded in the production of the first chromatographic supports and will soon test them for adenovirus purification.

The Nessie research project is believed to show that revolutionary technologies such as AM can improve healthcare systems in a sustainable way. The novel process makes vaccines available in countries where the high cost of essential vaccines such as measles or rubella currently makes them unaffordable. The research project partners state that with the current closure and shortage of medical supplies, Additive Manufacturing has proven that local manufacturing can be more than just making prototypes; AM is helping to quickly produce components regardless of location and without dependence on complex supply chains.

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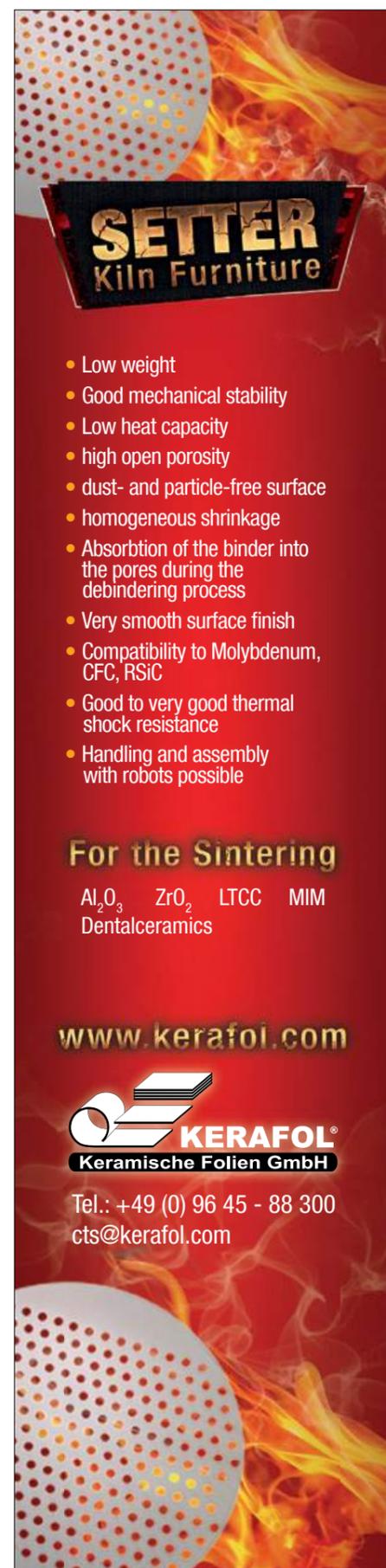


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Carpenter Technology to idle two powder production facilities

Carpenter Technology Corporation, headquartered in Philadelphia, Pennsylvania, USA, has stated it plans to idle two of its US-based metal powder production facilities, as the company reacts to the COVID-19 pandemic and an oversupply of titanium powder in the market. However, as stated by Tim Lain, Carpenter's Vice President & Chief Financial Officer, during the company's third quarter 2020 results conference call, Carpenter has no plans to exit the metal powder market. "We remain committed to a metal powder production, but consider it necessary to close these two facilities to save cost and preserve cash flow in the near term," he commented. The sites affected, reported to be Rhode Island and West Virginia, are set to close in the next quarter.

During a Q&A session in the conference call, Tony Thene, CEO, added, "Unfortunately, when we brought online our West Virginia facility there were many others that brought on titanium powder capacity, so that is in an oversupply position right now."

"We can still offer a full portfolio to customers," Thene confirmed during the conference call. The company also announced plans to exit the downstream oil and gas (Amega West) business.

"We expect that the actions to exit the Amega West business and idle the two powder facilities will generate estimated annual savings of \$15 million to \$20 million based on the current run rates for these businesses," added Lain.

www.carpentertechnology.com ■

Kymera closes deal to buy Reading Alloys

Speciality materials company Kymera International, Raleigh, North Carolina, USA, has closed its transaction with Ametek, Inc., Berwyn, Pennsylvania, USA, to acquire 100% of the shares of the Reading Alloys business.

Founded in 1953 and acquired by Ametek in 2008, Reading Alloys designs, develops and produces master alloys, thermal barrier coatings and titanium powders. The business is a supplier for producers of high-quality titanium and super alloy mill products that are used in aerospace and aircraft applications.

Kymera has been owned by affiliates of Palladium Equity Partners, LLC, New York, New York, USA, a middle-market private equity firm with approximately \$3 billion in assets under management, since 2018. The terms of the transaction were not disclosed.

"Reading Alloys is an outstanding company with highly-skilled people and an excellent product and end-market portfolio that fits in perfectly with our existing business," stated Barton White, CEO of Kymera.

"For Kymera, we believe this is a transformative acquisition that will give our combined company strong technical and commercial resources to help fuel our growth in the aerospace, defence, medical and industrial markets."

"The acquisition of Reading Alloys, Kymera's third to date under Palladium's ownership, is right on strategy as the Kymera management team continues to build the company into a leading specialty materials producer," commented Adam Shebitz, a Partner at Palladium.

www.kymerainternational.com ■

20th Plansee Seminar postponed

Plansee Group, headquartered in Reutte, Austria, has postponed its 20th Plansee Seminar, the International Conference on Refractory Metals and Hard Materials, until 2022 due to the disruption caused by the coronavirus (COVID-19). The seminar was originally scheduled to take place at the group's Reutte headquarters from June 7-11, 2021.

In a statement, Karlheinz Wex, Chairman of the Plansee Seminar, wrote, "We, the Chairman of the Plansee Seminar and the whole Scientific Committee, have now decided to postpone the 20th Plansee Seminar by one year to 2022."

"We hope that by then we will be able to hold the conference, which is characterised by a high level of free and direct social exchange and communication, as you have been accustomed to. We believe that you comprehend our decision and we hope to heartedly welcome you to the 20th Plansee Seminar in Reutte in 2022."

www.plansee-seminar.com ■

EPMA's 20th PM Summer School to take place in 2021

Due to the implications caused by the coronavirus (COVID-19), the European Powder Metallurgy Association (EPMA) has rescheduled its 20th PM Summer School to July 2021. The Summer School was originally set to take place at the University of Castilla la Mancha, Ciudad Real, Spain, on July 20-24, 2020. The event location remains the same and the date is yet to be confirmed.

The five-day residential course is open to young scientists, designers and engineers looking to gain a broader knowledge and understanding of the Powder Metallurgy process and applications.

www.summerschool.epma.com ■

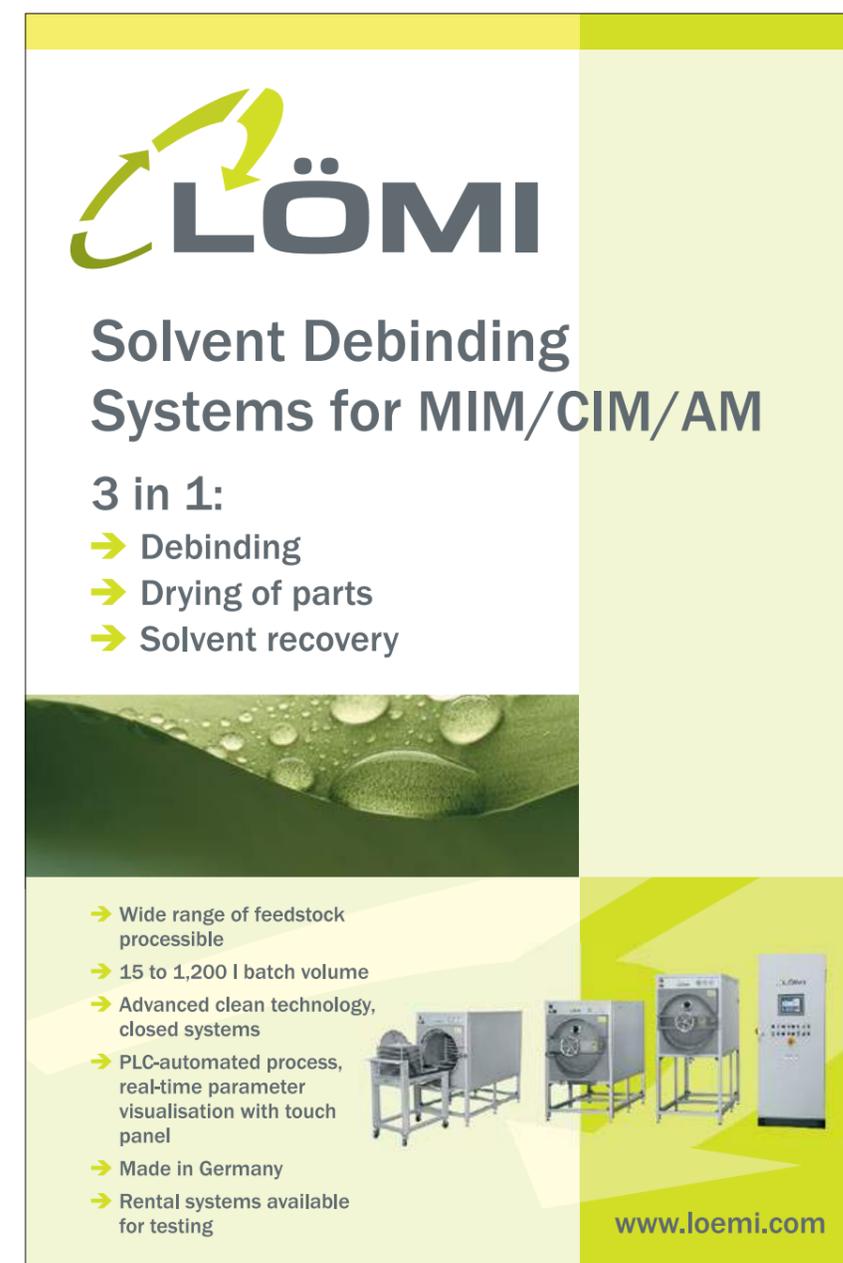
New dates for China's largest PM exhibition announced

The 13th International Exhibition for Powder Metallurgy, Cemented Carbides and Advanced Ceramics (PM China 2020), organised by Uniris Exhibition Shanghai Co., Ltd, has been moved to August 12-14, 2020.

Originally set to take place from March 24-26, 2020, over 500 organisations are reported to have reserved booths at the

event. "We once again apologise for any inconveniences caused to you by the postponement and are sincerely grateful for your kind understanding and continual support. We look forward to seeing you on August 12-14, 2020, at Shanghai World Expo Exhibition Center," the organisers stated.

www.pmxchina.com ■



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Parmatech to use HP Metal Jet technology for Cobra Golf

HP Inc., Palo Alto, California, USA, has announced golf club manufacturing company Cobra Golf as a new customer for its Metal Jet Additive Manufacturing technology. The company selected HP's Metal Jet Binder Jetting technology as it looks to leverage the benefits of sinter-based AM.

Cobra is said to be committed to advancing golf club technology, engineering first-of-their-kind clubs and equipment designed to elevate the sport. Cobra, HP, and HP's Metal

Jet Production Service partner Parmatech, are now said to be working together on a strategic, multi-year product roadmap that will leverage the design and manufacturing benefits of HP's AM technologies to deliver golf equipment that enhances player performance and satisfaction.

"Cobra Golf strives to deliver high-performance products that help golfers of all levels play their best and enjoy the game," stated Jose Mirafior, Vice President of

Marketing, Cobra Golf. "To do that, it's critical to use the most effective manufacturing processes to design, develop, and achieve optimal results."

"To continue innovating and transforming the way equipment is manufactured, we are working with HP and Parmatech to take advantage of the benefits of Metal Jet," he explained. "We are seeing immediate benefits including design freedom, rapid design iteration, and high quality parts that meet our economic demands."

www.parmatech.com
www.hp.com/go/3Dprinting
www.cobragolf.com



GKN PM partners with Workerbase on data-driven manufacturing

GKN Powder Metallurgy and Workerbase have entered a partnership which aims to accelerate the transformation of the manufacturing industry and prepare for the new business environment post-coronavirus (COVID-19). Under the partnership, the two companies have created what is described as an agile, data-driven production system.

The COVID-19 pandemic has had a significant short- and long-term economic impact on the global manufacturing industry. In a recent survey, the National Association of Manufacturers revealed that, as of March 2020, 53% of organisations in the manufacturing sector expected COVID-19 to change their operations over the coming months and 35% are currently facing supply chain disruptions.

The ability to operate in a rapidly changing business environment, explained GKN Powder Metallurgy, requires organisations to adapt quickly. Increasingly, dynamic customer requirements are driving increased complexity and the need for shorter development and product life cycles. COVID-19's impact on the supply chain has accelerated

these trends and many companies now need to adapt to increasingly challenging market conditions.

Through fifteen years of research and implementation, GKN Powder Metallurgy stated that it has identified the most important question that manufacturing companies must ask themselves: "How can we acquire real-time data from production processes for full production transparency while still empowering our employees to act on the data in real time?"

The new system developed by GKN PM and Workerbase, a leading software provider in the field of agile production systems, is said to implement adaptive processes that allow for quick responses to evolving customer requirements and increasing competitiveness, while reportedly adding value for both shareholders and employees.

"Agile manufacturing has revolutionised our production and has structured how we want to run our operations in the future," commented Paul Mairl, Chief Digital Officer, GKN Powder Metallurgy. "The new normal of manufacturing requires a new way of working. Our partnership

with Workerbase is an important step on our journey to create a new vision of manufacturing operations: combining a data-driven culture with the best technology and technical solutions."

According to the partners, for the new way of working in manufacturing, the traditional role- and hierarchy-based organisational structure is replaced by a setup which is skill- and competency-based.

This organisational move relies on employees taking personal responsibility for their own performance and a self-learning working environment. By utilising technology like mobile devices on the production floor, employees are said to be able to challenge their skill levels and increase their productivity by performing work in a more efficient environment.

While digital manufacturing has made significant improvements to operations in the past, GKN PM stated that recent industry-changing circumstances have shown that a data-driven approach is now more crucial than ever to any production-based organisation. An agile manufacturing strategy is expected to provide the greatest opportunity to reinvent the way companies operate.

www.gknpm.com
www.workerbase.com ■

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SmarTech analysis estimates ceramic AM market to reach \$4.8 billion by 2030 in new report

SmarTech Analysis, Crozet, Virginia, USA, has released its latest report on the ceramic Additive Manufacturing market, titled 'Ceramics Additive Manufacturing Part Production: 2019-2030'. The report suggests that despite significant disruptions caused by the coronavirus (COVID-19), the overall ceramics AM industrial sectors, including hardware, materials and application revenues (or revenue equivalent), is estimated to grow to \$4.8 billion by 2030. Final parts value for both technical and traditional ceramic parts is expected to continue to represent the most significant opportunities driving the market for the medium- to long-term future.

The report identifies the most commercially important AM technologies, material types and material

form factors, as well as application segments for ceramic AM, differentiating between technical and traditional ceramic materials. It presents an in-depth analysis of the different types of firms offering ceramic AM services and parts, including specific forecasts on ceramics AM service providers, ceramic additively manufactured parts providers and adopters.

According to SmarTech's predicted timeline, ceramic Additive Manufacturing adoption will experience an inflection point after 2025, as all major AM technologies that support ceramics final part production come to maturity and establish enough presence in the market to support actual serial production. The full report is available via the company website.

www.smartechanalysis.com ■

Industry veteran starts consulting company

MicroMet Technologies, a new consultancy covering the MIM, metal AM and PM industries, has been established in Wayland, Massachusetts, USA.

The company's President and CEO, John Gaspervich, has forty years of experience in the metal powder industry and has held technical, manufacturing, marketing and executive positions with firms such as Indo-US MIM Tec Pvt.Ltd., OptiMIM, and Veloxint.

MicroMet Technologies offers support to those evaluating, adopting and ramping the production or use of MIM, AM and PM across application sectors that include automotive, medical, consumer, industrial, aerospace and defence applications.

www.micromettech.com ■

EU's new harmonised classification for cobalt

The Cobalt Institute, a non-profit trade association composed of producers, users, recyclers, and traders of cobalt based in Guildford, Surrey, UK, has reported the EU's updated harmonised classification rules for cobalt metal, including a temporary Generic Concentration Limit (GCL) of $\geq 0.1\%$. The new rules entered into force on March 9, 2020, and will apply from October 1, 2021. The cobalt industry is reportedly working with its downstream users to ensure an effective implementation of the new harmonised classification.

The Cobalt Institute believes that EU regulation should focus on the established hazard concerns linked to the inhalation of cobalt metal. However, despite existing data reportedly indicating the safety of dermal and oral exposure to cobalt metal, the new harmonised classification is not limited to inhalation. As a consequence, the cobalt industry plans to invest significant additional resources to generate new scientific evidence to conclusively prove that cobalt metal can be used safely once exposure via inhalation is controlled.

The Cobalt Institute explains that it welcomes the European Commission's recognition, through the temporary GCL, of the need to further refine the methodology for deriving concentration limits for inorganic materials such as cobalt metal. The association encourages the EU and member state authorities to continue to engage in the expert group which has been established to review this methodology under the European Chemicals Agency. In the meantime, the CI reports that it will be important in its view to maintain the current GCL, the appropriateness of which it is confident will be confirmed by the ECHA review.

www.cobaltinstitute.org ■

MIM2021 issues call for papers

A call for presentations has been issued for MIM2021: International Conference on Injection Molding of Metals, Ceramics and Carbides, to be held in West Palm Beach, Florida, USA, February 22-24, 2021. Presentation submissions will close on September 30, 2020.

The conference is sponsored by the Metal Injection Molding Association, a trade association of the Metal Powder

Industries Federation, and its affiliate APMI International. Highlights of the 2021 event include a full programme of both high-level technical research and commercially-oriented presentations, tabletop exhibition & networking reception, and the annual PIM Tutorial, presented by industry veteran Randall M German.

Authors wishing to present a paper at MIM2021 should submit an abstract using the submission form, which can be downloaded via the conference website.

www.mim2021.org ■

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Europe: Email: InfoEU@indo-mim.com Ph: +49 1732656067
Asia: InfoHQ@indo-mim.com Ph: +91 98459 47783 / +91 98450 75320

MPIF cancels WORLDPM2020, AMPM2020 and Tungsten2020 due to coronavirus

The Metal Powder Industries Federation (MPIF) has announced that the 2020 World Congress on Powder Metallurgy & Particulate Materials (WorldPM2020), the 2020 Additive Manufacturing with Powder Metallurgy conference (AMPM), and the 10th International Conference on Tungsten, Refractory & Hardmaterials (Tungsten2020), which were scheduled to take place concurrently in Montréal, Canada, from June 27–July 1, 2020, have been cancelled due to the spread of coronavirus (COVID-19). In an official statement, Jim Adams,

the MPIF's Executive Director/CEO, wrote, "After thoughtful deliberation, it is with a sad and heavy heart that a decision has been made to cancel the WorldPM2020, AMPM2020, Tungsten2020 conferences to have taken place June 27–July 1 in Montréal. The conferences will not be rescheduled." "Our technology's advancement is greatly affected by the lost opportunity for our speakers to present the latest research and to collaborate with colleagues. Our suppliers and service providers are unable to present the cutting-edge advance-

ments in materials, equipment, and services. However, all speakers and exhibitors have been encouraged to share these technology advancements next year at PowderMet2021 and AMPM2021, June 20–23, 2021, in Orlando, Florida, USA. Unfortunately, the 10th Tungsten, Refractory and Hardmaterials conference will not be held in 2021."

Adams added, "We are grateful to everyone who has worked tirelessly with planning, promoting, and supporting the Montréal conferences, the Metal AM Tutorial, and all other conference activities. We ask for your patience as we work diligently to address questions and provide additional information to all who are impacted by this cancellation."

www.mpif.org ■

Prof Herbert Danninger to receive 2020 Ivor Jenkins Medal

The UK's Institute of Materials, Minerals and Mining (IOM³) has named Prof Herbert Danninger as the recipient of its 2020 Ivor Jenkins Medal. As Professor for Chemical Technology of Inorganic Materials at Technische Universität Wien (TU Vienna), Austria, Prof Danninger has been Dean of the Faculty of Technical Chemistry for eight years. He holds lectures about Chemical Technology, Powder Metallurgy, and Materials Science and Technology. In an academic career spanning over forty years, he has published around 520 scientific articles in peer-reviewed journals, as well as in proceedings of international conferences, predominantly on Powder Metallurgy.

"I feel very honoured to be awarded the Ivor Jenkins Medal," Prof Danninger stated. "I had the pleasure to meet Ivor Jenkins personally on numerous occasions, in particular the 'Powder Metallurgy Group Meetings' held in the 1980s every October."

Graduating as an engineer (Dipl.-Ing.) from TU Vienna in 1979, he went on to complete his doctoral thesis (Dr. techn.) at the Institute for Chemical

Technology of Inorganic Materials in 1980. He was later made head of the Powder Metallurgy Laboratory at the Institute in 1993 and became Associate Professor (Ao.Univ.Prof.) in 1997.

In 2002 he was named head of the Chemical Technologies Division at Institute of Chemical Technologies and Analytics and a year later was appointed to Full Professor for Chemical Technology of Inorganic Materials. Danninger became Director of the Institute of Chemical Technologies and Analytics in 2004 and Dean of the Faculty of Technical Chemistry in 2011.

In addition to the Ivor Jenkins Medal, Prof Danninger has received numerous international awards in recognition of his work. These have included the Skaupy Lecture Award of the Gemeinschaftsausschuss Pulvermetallurgie, Germany, in 2006, the APMI Fellow Award from APMI International, Princeton, New Jersey, USA, in 2010 and was named a Fellow of the EPMA in 2018.

www.iom3.org ■

EPMA Virtual Congress to replace Euro PM2020 in light of coronavirus

The European Powder Metallurgy Association (EPMA) has confirmed that, due to coronavirus, a Virtual Congress will be held in place of Euro PM2020, originally scheduled for Lisbon, Portugal, October 5–7.

The new online event is expected to allow all 300+ technical papers to be presented during a live webinar, and is scheduled to take place over the same dates as the original congress (October 5–7, 2020).

It was stated that given the difficulties participants may have travelling to Lisbon, as well as the high safety and financial constraints of running a live meeting in 2020, the EPMA Board had decided to postpone the live Euro PM Congress & Exhibition event. Euro PM2021 will now take place in Lisbon, Portugal, October 17–20, 2021.

www.europm2020.com ■



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Triditive plans 1,700 m² factory for production of its AM machines

Triditive, Gijón, Spain, will open a 1,700 m² factory in Siero, Spain, for the production of its AMCell Additive Manufacturing machines. The factory is expected to be the largest AM-focused plant in Spain. The announcement comes after the company received an investment from US-based Stanley Ventures, the venture capital team of Stanley Black & Decker, Inc., and Sadim Inversiones, an economic promotion company based in Ujo, Spain, enabling plans for the facility to go ahead.

AMCell is described by Triditive as the first automated '3D Factory in a Box' and integrated with EVAM, a software platform for remote control and automatic production optimisation, to automate and manage the entire Additive Manufacturing workflow in a single platform.

The machine is powered by Automated Multimaterial Deposition (AMD) Technology® and uses a process similar to Metal Injection Moulding to produce green parts, with the advantages of the Material Extrusion (MEX) AM processes (also referred to as Fused Deposition Modelling and Fused Filament Fabrication). The result is said to be a process with the highest

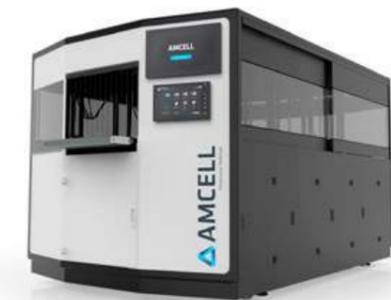
throughput of cost-efficient metal parts. The modular AMCell series is composed of an Additive Manufacturing module, quality control and automatic storage modules, and customers can configure it depending on their needs, adding as many modules as they need to scale up production capacity.

The company has already sold several of its AMCell machines to the Spanish Army and to Stanley Black & Decker for its USA factories. Stanley Ventures delivers access to breakthrough technologies and innovation partnerships across Stanley Black & Decker's businesses as a strategic investor that

accelerates growth and collaboration around the globe through a diverse portfolio of companies.

The investment from Stanley Ventures follows Triditive's presentation of the AMCell at the Stanley + Techstars Accelerator Demo Day in Hartford, Connecticut, USA, in October 2019. Triditive is said to be the first Spanish company in which Stanley Ventures has invested. Mariel Diaz, Triditive's Founder and CEO, stated, "We will create the largest AM Factory in Spain! 20,000 ft² to create technology, employment, and add value to our customers. Thanks to our investors Stanley Ventures, Sadim Inversiones and Techstars for the support!"

www.triditive.com
 www.stanleyventures.com
 www.sadiminversiones.es ■



AMCell is described by Triditive as the first automated '3D Factory in a Box' (Courtesy Triditive)

Rapidia to serve US Additive Manufacturing customers from new Chicago facility

Rapidia Inc, headquartered in Vancouver, British Columbia, Canada, has opened a new US facility in Innovation Park, just outside Chicago, Illinois, to showcase its Additive Manufacturing technology and serve its US customers. The Rapidia system uses a water-based metal paste AM process to produce parts in a range of materials, including stainless steel, Inconel, and ceramics.

The two-stage, office-friendly system consists of a metal AM system and a sintering furnace. The use of water, instead of a typical binding element, eliminates a solvent-based debinding step and is said to result in a fast, simple to use system that is environmentally friendly and completely solvent-free.

With the opening of its US facility, Rapidia also announced the appointment of Tim Ruffner as its new Head



Rapidia's new US facility is based in Chicago, Illinois (Courtesy Rapidia)

of North American Sales. Ruffner has a background in Additive Manufacturing, having previously worked for Desktop Metal, Concept Laser, Rize and Dynamism.

www.rapidia.com ■

Formnext + PM South China has support from German manufacturing groups

Formnext + PM South China, scheduled to take place September 9–11, 2020, in Shenzhen, China, has announced official partnerships with the Aachen Center for Additive Manufacturing (ACAM) and the Verband Deutscher Maschinen-und Anlagenbau (VDMA), two of the most recognised advanced manufacturing groups in Germany. This strategic collaboration is expected to bring benefits to the Chinese market by showcasing some of the most recent technologies and products in Additive Manufacturing, Powder Metallurgy and advanced ceramics from Germany.

The Formnext + PM South China event is targeted at the Additive Manufacturing, Powder Metallurgy and advanced ceramics sectors and will take place at the Shenzhen World

Exhibition and Convention Center. Located in one of the key cities of the Greater Bay Area of China, the show will put a strong focus on the Chinese market and cover an array of AM solutions and materials, smart manufacturing technologies and equipment, PM products, ceramic materials and forming technologies, post-processing solutions and more.

Formnext + PM South China's mission is to shorten the manufacturing cycle time with lower cost and higher quality by integrating advanced materials, equipment and technical solutions into the manufacturing process, the organisers are bringing this to the fore through the cooperation with ACAM and the VDMA. ACAM will co-organise the Discover 3D Printing Seminar during the fair and showcase the latest Additive

Manufacturing technologies and applications in Germany. VDMA will group its members in a pavilion to expand their overseas market, and to boost development for enterprises in the Chinese manufacturing industry.

Dr-Ing Kristian Arntz, Managing Director and Partner of ACAM, and Dr Markus Heering, Managing Director of the Additive Manufacturing Working Group of VDMA, also expressed their excitement about the new fair. "ACAM are excited about Formnext + PM South China, and will offer our services covering further education for companies as well as consulting and developments in the relevant areas of Additive Manufacturing to Chinese and other Asian manufacturing industries. We expect it to be a great show as the market is emerging and Additive Manufacturing is becoming more and more important to many companies in this area," he stated.

www.formnext-pm.com ■

3DEO reports 600% revenue growth in 2019

3DEO, Inc., a metal Additive Manufacturing technology company based in Los Angeles, California, USA, has announced a 600% growth in revenues for 2019 over 2018. The company also reported a 394% increase in the number of additively manufactured parts shipped in 2019, with approximately 25% of parts being for aerospace, 35% for medical and 40% for defence applications.

The number of employees at 3DEO was also reported to have increased to sixty, up 172% compared to the twenty-two employees in 2018. AM machines used at 3DEO for part production were said to have increased by 566%. 3DEO's printers are built with proprietary technology, specialised for serial production and manufactured in the USA.

"We are very proud of the growth that was accomplished over the last

year," stated Matt Sand, President of 3DEO. "It is clear that 2020 will be another record-setting year for 3DEO as our pace of adoption across all industries is accelerating. More than a metal 3D printing company, 3DEO is a solutions provider helping our customers tackle their most challenging manufacturing problems."

The company started as an Additive Manufacturing business with its patented metal AM technology, Intelligent Layering®, at its core. However, in order to compete in high-volume traditional manufacturing, the company stated it evolved into a vertically integrated, next generation factory. This new business model allows manufacturers to gain the cost savings, design freedom, and manufacturing flexibility needed to compete – without having to incur millions of dollars for a metal AM machine and the supporting infrastructure.

Amidst a downcycle in manufacturing jobs in America, 3DEO reports that its new solution-focused business model is creating new jobs. High-tech production workers work

with robotics and automation and its most noteworthy employee increase was in the R&D department. With over twenty-five engineers, 3DEO states it is continuously improving core processes and technology up and down the production line.

Sand added, "What's more, almost every customer we are working with is using metal 3D printing in production for the first time. We are in the trenches with our customers, and our growth curve is a testament to the demand for these solutions. In the end, our mission is to do for manufacturing what Amazon's AWS did for the internet by offering low-cost access to flexible, scalable, and world-class manufacturing infrastructure."

Matt Petros, 3DEO's CEO, commented, "We're doing things in manufacturing that previously couldn't be done. And we're doing it by leveraging several enabling technologies that are converging right now in manufacturing – in a way that finally allows metal 3D printing to shift the serial production paradigm."

www.3deo.co ■



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Digital Metal launches software upgrade said to triple its AM machine build speeds

Digital Metal, part of Sweden's Höganäs Group and a developer of metal Binder Jet Additive Manufacturing machines, has launched a new software upgrade which it states triples the build speed of its DM P2500 machines. The upgrade reportedly enables significantly larger production volume per time unit while maintaining high component quality. The new software is now standard on all new units, and upgrade kits are available for installed machines.

According to, Digital Metal, its new DM P2500 metal Binder Jetting machine has been made to be as

accurate as possible, with all moving parts having an accuracy down to single microns, said to enable excellent repeatability in serial production. In addition, a 160 mm thick custom-made diabase stone is now incorporated to heighten stability and ensure no vibrations affect the Additive Manufacturing process.

"We constantly work to improve the performance of our printers so that our customers can work as cost-effectively as possible," stated Alexander Sakratidis, Sales & Marketing Manager at Digital Metal. "This important upgrade



Digital Metal has launched a software upgrade said to triple the Additive Manufacturing speed of its DM P2500 machine (Courtesy Digital Metal)

makes it possible to reach even greater production volumes without sacrificing component quality. We plan to continue introducing similar significant upgrades twice a year." www.digitalmetal.tech ■

Formatec adds Metal Injection Moulding to its portfolio of manufacturing processes

Formatec BV, based in Goirle, the Netherlands, has added Metal Injection Moulding to its manufacturing portfolio. Through this addition, the Ceramic Injection Moulding specialist states that it can even better serve customers through a more diversified range of technologies. By assembling a new team of MIM experts, Formatec stated that it is confident to be able to offer metal parts and products to the same quality that its customers are used to in ceramic.



MIM components manufactured by Formatec (Courtesy Formatec)

All of Formatec's R&D and production is undertaken in-house at its facility in the southern Netherlands. "After some years of small-scale MIM production of refractory metals like tungsten, we decided to expand our production staff by acquiring a team of MIM experts. At Formatec we can now offer the same high level of knowledge and expertise as we do in Ceramic Injection Moulding and Additive Manufacturing," stated Jaco Saurwalt, Formatec's COO.

René Bult, General Manager at Formatec, added, "I'm excited that we can finally announce the expansion of our production capabilities with MIM as we can now provide an even better, well-rounded array of manufacturing methods to our customers. Their demand is what drives our developments and I'm looking forward to start working on new challenging projects with them."

www.formatec.nl ■

Lithoz supplies Fraunhofer IKTS with its third CeraFab machine

Lithoz GmbH, Vienna, Austria, recently reported that the Fraunhofer Institute for Ceramic Technologies and Systems (IKTS), headquartered in Dresden, Germany, has installed its third CeraFab ceramic AM machine. Fraunhofer IKTS is Europe's largest R&D institute at the forefront of developing high-performance ceramic materials and manufacturing processes.

The CeraFab System can incorporate up to four production units with an increased build speed compared to previous models, allowing for a significant increase in productivity. A central element of the CeraFab System creates a database for storing and handling process data, which facilitates the seamless documentation of build jobs. Furthermore, machine and process monitoring is carried out in real time.

www.lithoz.com
www.ikts.fraunhofer.de ■



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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)

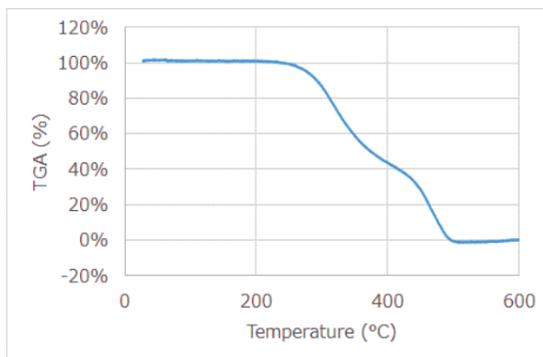


Fig.3 TGA Curve of Binder

※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.

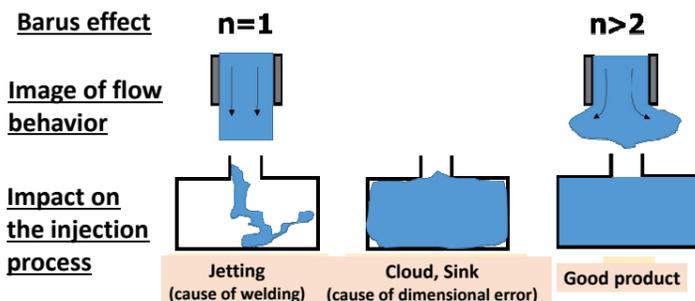


Fig.1 Schematic of the relationship between n value and flow characteristic

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

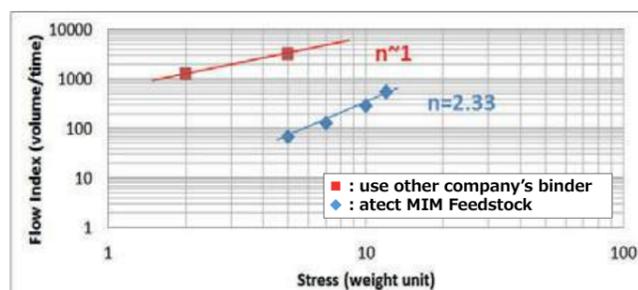


Fig.2 Flow characteristic compared with pellets using the other company's binder

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

ExOne and Pittsburgh University produce additively manufactured metal filters for reusable respirators

The ExOne Company, North Huntingdon, Pennsylvania, USA, has collaborated with the University of Pittsburgh, Pennsylvania, USA, to develop reusable porous metal additively manufactured filters that fit into a specially designed plastic respirator cartridge for sustainable, long-term protection against contaminants, such as coronavirus (COVID-19).

By utilising its Binder Jetting technology, ExOne states that it has additively manufactured respirator filters in two metals, copper and 316L stainless steel, and a range of porosity levels for use inside a unique cartridge designed by the Mechanical Engineering & Materials Science department in the Pitt Swanson School of Engineering, part of the University of Pittsburgh. Initial testing for airflow and filtration efficiency is believed to be underway, and the filters are being optimised with the goal of adhering to an N95 respirator standard.

"Our team has been working urgently to expedite this promising and reusable solution for medical personnel on the frontlines of fighting the COVID-19 pandemic," stated

John Hartner, ExOne CEO. "Our customers routinely print porous metal filters for a variety of purposes, and we are confident that we'll have a solution soon that can enable medical personnel to sterilise metal filters for repeated reuse, eliminating waste. Once approved, we can print these filters in a variety of sizes for respirators, ventilators, anesthesia masks or other equipment."

"The advantage of binder jet 3D printing over other Additive Manufacturing methods for this filter application is the ability to utilise the porosity of the printed part and then fine tune it during the high temperature densification or sintering process to achieve optimum filtering and airflow performance," explained Markus Chmielus, Associate Professor of Mechanical Engineering and Materials Science at the Swanson School.

ExOne's Binder Jetting technology uses an industrial printhead to selectively deposit a liquid binder onto a thin layer of powdered material, layer by layer, until a final object is formed. After additively manufacturing powdered metals, the object is

then sintered in a furnace to dial in a specific level of porosity. While binder jetted metal is typically sintered to full density, some applications require a specific level of porosity, such as filters.

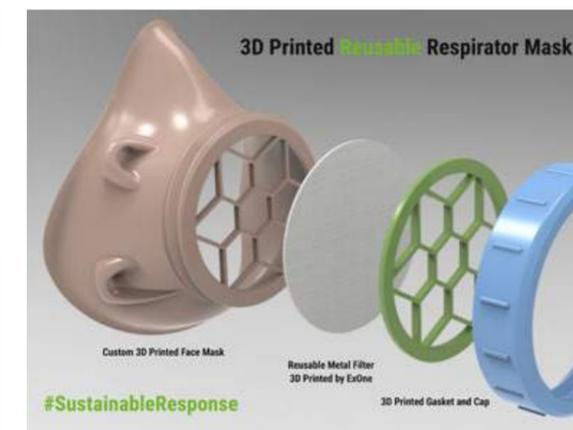
To test filters in different metals and porosities, Dr Chmielus' research group is using CT scanners to analyse the microstructure and porosity of the filters. Ansys, a global leader in engineering simulation, also based near Pittsburgh, is providing additional computer simulation support to analyse and optimise the performance of the filters.

ExOne explains that while copper and stainless steel filters are currently being tested, copper has been recognised for its antibacterial properties for some time. The first recorded instance of using copper to tackle germs was in the Edwin Smith Papyrus, said to be the oldest known medical document in history, according to the Smithsonian. The company goes on to say that many studies have also proven copper's disinfectant powers. One landmark 2015 study, funded by the Department of Defense, revealed that copper alloys contributed to a 58% reduction in infections and COVID-19 research also suggests the virus dies faster on copper than on other surfaces.

www.exone.com
www.engineering.pitt.edu



ExOne has additively manufactured filters in copper, as well as stainless steel, to test different porosities, airflows and filtration capabilities (Courtesy The ExOne Company)



ExOne additively manufactured a reusable, sterilisable copper filter to fit inside a cartridge designed and additively manufactured by Pittsburgh University (Courtesy The ExOne Company)

Cetim announced as early adopter of Desktop Metal Shop System

Cetim, the Technical Centre for Mechanical Industry, based in Cluses, France, and Desktop Metal, Burlington, Massachusetts, USA, have announced that Cetim, which works closely with industrial companies to help identify market opportunities and facilitate innovation and technical progress, will become one of the first adopters of the new Desktop Metal Shop System™, a metal Binder Jetting system designed for machine and metal job shops.

The move follows Cetim's installation of a Desktop Metal Studio System at its Cluses facility. Using both the Studio System, designed for the rapid prototyping and low-volume production of metal AM parts, and now the Shop System, Cetim's customers in aerospace, oil & gas, automotive and other industries, are expected to be able to explore new, advanced solutions for their manufacturing needs – from low-volume prototyping to mid-volume runs of complex metal parts.

"As the demand for metal AM continues to grow, it is challenging for many of the mechanical industry companies we work with to identify the right solution that meets their needs and then to implement it in an effective and cost-efficient way,"

explained Pierre Chalandon, Cetim's Chief Operating Officer.

"Desktop Metals technologies, with both the Studio System and new Shop System completes our Additive Manufacturing machines park," he continued. "From a general point of view, metal Binder Jetting technology is promising for a large part of our clients. Desktop Metal's solutions portfolio covers the full metal product lifecycle, which is complementary to our experience on sintered material and finishing operations."

In addition to the implementation of both the Studio System and Shop System, Cetim and Desktop Metal reported that they plan to collaborate on a variety of research initiatives, including design for metal AM, post-processing and finishing techniques qualification, workflow optimisation and materials development, among others.

The Shop System, launched during Formnext 2019, is said to enable shop owners to take advantage of affordable, high-quality Binder Jetting technology to build end-use metal parts at high speeds, to a high quality and at high productivity. With Shop System machine prices starting at \$150,000, the machine is expected to enable shop owners to eliminate many of the constraints previously



A worker at Cetim uses Desktop Metal's Studio System (Courtesy Desktop Metal)

seen with conventional manufacturing methods like CNC machining, and tap into new opportunities to reduce costs and increase revenue.

"When it comes to empowering industrial companies with the Additive Manufacturing technologies of the future, Cetim is truly one of the leaders in Europe," commented Ric Fulop, CEO and co-founder, Desktop Metal. "We are excited to partner with Cetim as one of the first customers for our ground-breaking Shop System, and are eager to collaborate with Cetim on our shared efforts to change the way that companies manufacture around the globe."

Cetim operates with a range of different platforms and associated partners, covering almost all direct and indirect Additive Manufacturing technologies including Laser Beam Powder Bed Fusion (LB-PBF), Wire Arc Additive Manufacturing (WAAM), and Binder Jetting (BJT). The centre is also strongly involved in the international normalisation of metal Additive Manufacturing, and coordinates AFH, the initiative Additive Factory Hub, which aims to innovate, develop and integrate AM to address the key industrial and economic challenges.

www.cetim.fr

www.desktopmetal.com



The Desktop Metal Shop System and furnace (Courtesy Desktop Metal)



MIM & CIM Process

Metal and Ceramic Injection Molding



Metalpine opens new production site for highly-spherical metal powders

Metalpine GmbH, Graz, Austria, a manufacturer of metal powder and part of the htm Group (hightech metal investment GmbH), has opened a new production site based at its Graz headquarters, which will primarily produce highly-spherical metal powders for use in Additive Manufacturing. An opening ceremony for the plant was attended by numerous representatives from politics, science and business including Dr. Karl-Heinz Dernoscheg, WKÖ Steiermark; Dr Robert Brugger, ICS Styria; Dr Gerald Sitte, Spaceone; and Klaus Fronius and Brigitte Strauss, Fronius.

According to the company, the total capacity of the new production site will gradually be increased to 400 tons per year and, using the in-house developed process, metal powders can reportedly be produced in a unique quality from a very wide range

of metals and metal alloys (including copper, steel, nickel-base alloys, titanium, molybdenum, tungsten, etc).

Metalpine states that all its materials are produced using a flexible, environmentally friendly inert gas process under cleanroom conditions, and are aimed at highly-demanding applications such as Laser Beam Powder Bed Fusion (LB-PBF), metal sintering, powder build-up welding or surface coatings.

Additionally, the new production site is believed to have a good network for industrial and academic research and development in the field of Additive Manufacturing, with research in the areas of production processes, materials and fields of application being carried out by the Montanuniversität Leoben and the Graz University of Technology.

www.metalpine.at ■

MTC signs MoU with Lucideon to develop ceramic AM in the UK

The National Centre for Additive Manufacturing (NCAM), based at the Manufacturing Technology Centre (MTC) in Coventry, UK, reports that it has signed a Memorandum of Understanding (MoU) with Lucideon Limited, a materials consultancy located in Stoke-on-Trent, Staffordshire, UK. The aim of the MoU is to develop AM technologies and their applications in the ceramics industry, with the ambition of establishing the UK as a centre of excellence for ceramics AM.

The MTC explains that, while the UK has some experience of using AM in ceramics, it is not widespread. MTC and Lucideon will together to explore materials technology and share access to facilities, whilst encouraging ceramics businesses to improve productivity and production processes using AM.

The NCAM at the MTC brings together one of the most compre-

hensive combinations of Additive Manufacturing equipment and capability in the UK, and is also home to the European Space Agency's Additive Manufacturing Benchmarking Centre. Lucideon, which was established in the 1940s as the British Ceramics Research Association, specialises in materials technology and processes across several industries, combining materials science with innovative ideas and commercial know-how to improve productivity, cost and product performance.

"Additive Manufacturing is one of the fastest growing technologies in manufacturing and certainly has a future in the ceramics sector," stated Tom Wasley, NCAM Senior Research Engineer. "There is worldwide interest in the technology, so it is important that the UK explores how technology can provide a competitive edge."

<http://ncam.the-mtc.org/>
www.lucideon.com ■

EPMA to host free webinar series throughout 2020

The European Powder Metallurgy Association (EPMA) reports that registration will soon open for its new series of PM webinars. The free webinars will explore key topics affecting Powder Metallurgy strands via presentations from industry, research and academia experts.

The EPMA states that webinars will also offer a unique look at how the EPMA promotes, represents and develops the Powder Metallurgy industry, as well as providing audience members with an opportunity to contribute to the future of the PM sector. The series will include the following webinars:

- Additive Manufacturing
July 7, 10:30-12:00 CEST
- Metal Injection Moulding
August 28, 09:00-10:30 CEST
- Hot Isostatic Pressing
September 8, 10:30-12:00 CEST
- Functional Materials
October 29, 10:30-12:00 CET
- Press & Sinter
November 12, 09:00-10:30 CET
- Hard Materials
December 15, 10:30-12:00 CET

Further information and registration details are available via the EPMA website.

www.epma.com ■

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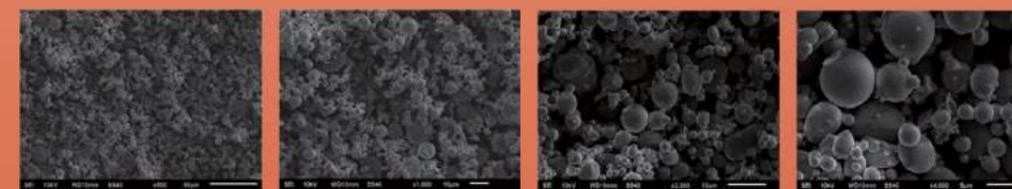
ADOPTING ADVANCED GAS AND WATER COMBINED ATOMIZATION TECHNOLOGY



Yingtan Longding New Materials & Technology Co., Ltd - Beijing Branch

The company provides various types of structural material powders, magnetic material powders, and other alloy powders in a variety of particle sizes and tap density based on the demands of the customers. The product line includes 316L, 304L, 17-4PH, 4J29, F75, HK30, 420W, 440C, Fe2Ni, 4140, and FeSi. The customers have received the products with high acclaim

Item	T.D(g/cm ³)	S.S.A(m ² /g)	S.D(g/cm ³)
316L	4.8	0.34	7.9
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



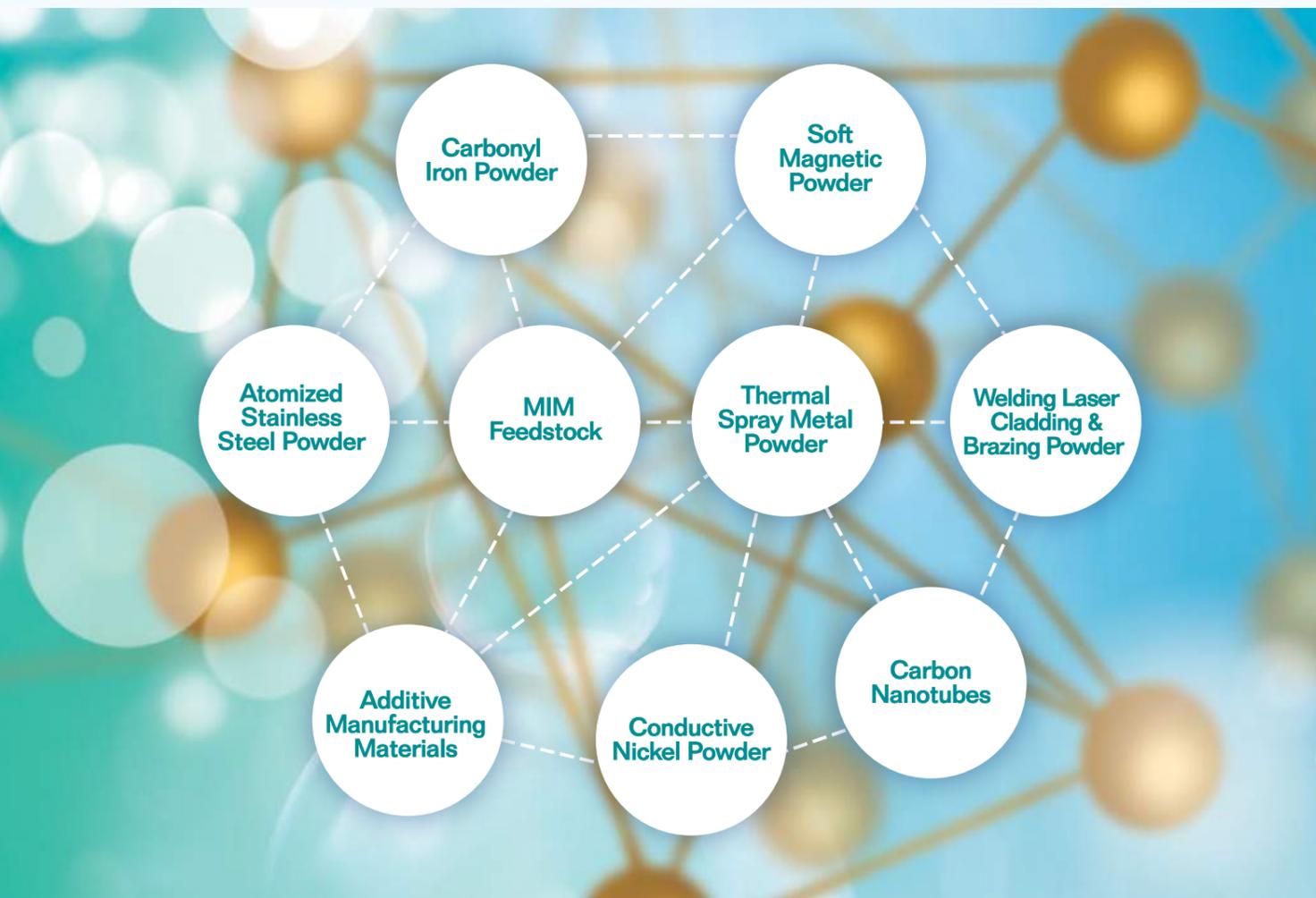
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JPMA announces new president and board structure

The Japan Powder Metallurgy Association (JPMA), based in Tokyo, Japan, announced the election of a new president and the appointment of a number of new board members at its General Assembly, May 18, 2020. Yoichi Inoue, Fine Sinter Co., Ltd., retired as president of the association and was succeeded by Nobuhiro Hashimoto, Sumitomo Electric Industries, Ltd.

Following his retirement from the presidency, Inoue remains a permanent member of the JPMA board. The current association membership is as follows:

President

- Nobuhiro Hashimoto Sumitomo Electric Industries, Ltd

Permanent Board Members

- Yoichi Inoue Fine Sinter Co., Ltd.
- Fumio Tsurumaki Diamet Corporation
- Shigeo Aoki Porite Corporation
- Hiroyasu Narukawa Kobe Steel, Ltd.

- Carl-Gustav Eklund Höganäs Japan K.K.
- Shuzo Sonoda Fukuda Metal Foil & Powder Co., Ltd.

Board members

- Junichi Takahashi Iwaki Diecast Co.,Ltd.
- Akihiro Matsunaga NTN Advanced Materials Corporation
- Takashi Suzuki NAPAC Co., Ltd.
- Masayoshi Nishimura Fukuisinter Co., Ltd.
- Soichiro Nakai JFE Steel Corporation
- Yoshiaki Mori Daido Steel Co., Ltd.
- Atsushi Nagano Dowa Electronics Materials Co.
- Jiro Bando Nippon Atomized Metal Powders Corporation
- Katsuhiko Nomura Mitsubishi Materials Techno Corporation



Nobuhiro Hashimoto, Sumitomo Electric Industries, Ltd., the new president of the JPMA (Courtesy JPMA)

Executive Director

- Yoshio Uetsuki

Auditors

- Yasushi Mori Nippon Atomized Metal Powders Corporation
- Yuichi Miyagawa Mitsubishi Materials Techno Corporation

Established in 1956, the JPMA today has over 180 member companies and works to generate industry statistics, coordinate PM research and promote the industry, among other activities.

www.jpma.gr.jp ■

Ampower releases its 2020 metal Additive Manufacturing report

Additive Manufacturing consultancy Ampower, Hamburg, Germany, has released the *AMPOWER Report 2020*. The independent market and technology report for metal Additive Manufacturing comprises an analysis of more than 250 data sets of personal surveys from suppliers as well as users of metal AM.

The report combines personal interviews with users and suppliers to the industry. The system suppliers that contributed represent over 90% of the worldwide installed base of metal AM machines. The users who contributed represent

over 13% of the globally installed base. According to the AM consultancy firm, in order to address the current economic situation during the coronavirus (COVID-19) pandemic, a separate section of the report analyses possible impact scenarios on the metal AM industry in 2020 and 2021.

In addition to the market data, new databases with over 700 entries were added in order to easily browse through a global list of system, service and material suppliers as well as AM machines. The application database was extended

to over sixty industrial Additive Manufacturing applications and the interactive cost calculator was updated with the latest productivity values.

www.am-power.de ■



Additive Manufacturing consultancy Ampower has released the *AMPOWER Report 2020* (Courtesy Ampower)

MIM technology applied to produce permanent magnets in Russia

High-coercivity alloys, based on the Fe-Co-Cr system, are used to produce permanent magnets having a unique combination of hysteresis characteristics and mechanical properties. The coercivity of these alloys reaches 500 – 600 Oe, which matches the level of cast Alnico 5 alloys. In contrast to other alloys used for permanent

magnets, high-coercivity Fe-Co-Cr alloys belong to a class of deformable hard magnetic materials suitable for working by pressure treatment (forging, rolling, etc) and machining. However, such magnets are often required in relatively small batches and in complex shapes, such as disks, rings or prisms, and this makes

their processing by traditional processes uneconomical. Powder Metallurgy production of Fe-Co-Cr magnets has been reported, using mixtures of elemental powders plus Mo, Si, V and other alloying elements to press billets, which are sintered in vacuum or protective atmosphere at a temperature of 1350 to 1430°C. Subsequent heat treatment involves homogenising, treatment for an α - solid solution with water quenching, isothermal thermomagnetic treatment (ITMT) in a magnetic field and multistage tempering. Magnetic properties are said to match those of Fe-Co-Cr alloys produced by casting. The disadvantages of the PM route are the high sintering temperature needed – above 1300°C – and the high cost of the starting powders produced by gas or plasma atomisation.

Metal Injection Moulding is considered to be an alternative to pressing and sintering for the production of complex shapes, and especially shapes with wall thicknesses as low as 0.5 mm, compared with the minimum of 2 mm that is possible with PM. A paper entitled: 'Problems of development of MIM technology in Russia as applied to production of permanent magnets' by S Yu Baydarov, *et al*, published in *Metal Science and Heat Treatment*, reports that the Spetsmagnit JSC in Moscow has been testing the production of 25Kh15KA permanent magnets by PM and MIM. The researchers stated that, in PM, blended powder mixtures were compacted to cylindrical shape compacts having 29.1 mm diameter and 11.5 mm length. These compacts were additionally compacted in a hydrostatic press at 1400 MPa, followed by sintering in hydrogen atmosphere at 1390–1420°C for 1.5 h.

The hysteresis loop measured for the cylindrical samples is shown in Fig. 1. The sintered magnets had the following magnetic characteristics: $B_r = 1.20 - 1.25$ T, $H_{cB} = 41.3 - 45.1$ kA/m,

$H_{cM} = 41.6 - 45.3$ kA/m and $(BH)_{max} = 38.2 - 40.3$ kJ/m³. These values were said to be higher than the standardised values (GOST 24897–81) for Fe-Co-Cralloy 25Kh15KA produced by casting.

The authors also reported that a MIM facility, installed at Production Association 'Start' after M V Protsenko in Zarechny, Russia, was also used to test the production of the Fe-Co-Cr permanent magnets with good functional properties and complex shapes. They stated, however, that to use the MIM process for the production of functional materials with specified magnetic properties requires detailed research into the fine details of the crystal structure and phase composition, which are sensitive not only to deviations from the optimum mode of heat treatment, but also to the presence of even low amounts of undesirable contents of C, S, O₂, etc. The magnetic properties of alloys of the Fe-Cr-Co system containing more than 0.1 wt.% carbon are said to degrade markedly.

The authors stated that the first obstacle encountered with the production of KhK-type permanent magnets using MIM is the absence in Russia of suitable ready granulated feedstock. Work at Production Association 'Start' after M. V. Protsenko therefore focused on developing an optimum blended mixture of elemental powders and binder using polyoxymethylene with additions of stearic acid. The granulate feedstock obtained, which contained metal powder blend with composition Fe–25Cr–15Co (in wt.%), was used to injection mould rectangular samples 4 x 6 x 39 and 12 x 12 x 6 mm in size using a specially designed mould for pressure casting. Following the second stage removal of the binder, the samples were sintered in vacuum at 1380°C for 1 h.

The sintered MIM samples were then heat treated to achieve a highly coercive state corresponding to decomposition of the α -phase into a nanosize (α' + α'') mixture of

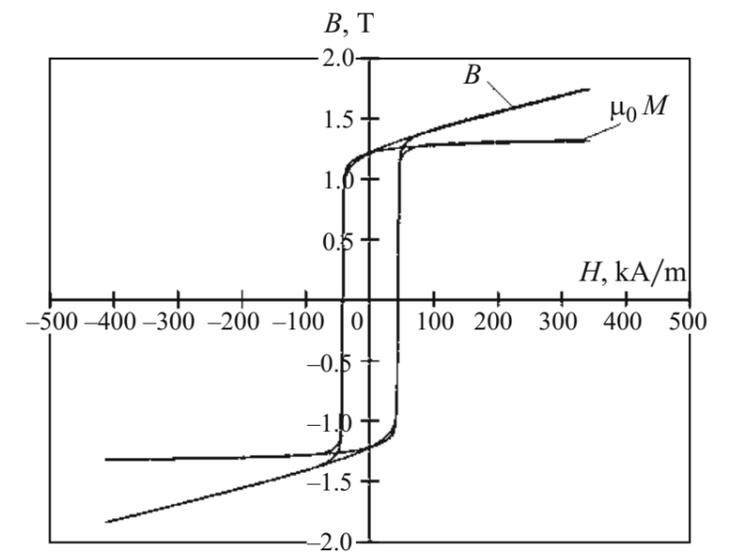


Fig. 1 Hysteresis loop of sintered Fe-Co-Cr alloy 25Kh15KA. (From paper: 'Problems of development of MIM technology in Russia as applied to production of permanent magnets', S Yu Baydarov *et al*, *Metal Science and Heat Treatment*, Vol. 61 No. 9–10, January 2020, pp 559–562

strongly and weakly magnetised phases. The heat treatment regime for the MIM Fe-Co-Cr magnets was as follows: homogenising at 1180°C with subsequent quenching for α - solid solution; ITMT at 640°C, 1 h + 620°C, 1 h; tempering at 600°C, 2 h + 580°C, 2 h + 550°C, 30 min. After heat treatment, the samples tested at the Production Association 'Start' after M. V. Protsenko and at Spetsmagnit JSC exhibited the following magnetic characteristics: $B_r = 1.12$ T, $(BH)_{max} = 23.0$ kJ/m³, $H_{cB} = 39.7$ kA/m.

The authors stated that further work needs to be done on the development of the intermetallics of the rare earth metals, in particular, for alloys of the Fe-Sm-Cr-Cu system (known in Russia as KS25) alloys for permanent magnets using the MIM process. This concerns the composition and the content of the polymer binder, the modes of removal of the binder, sintering and heat treatment. For example, it has been shown that following the removal of the polymer binder

from this type of alloy, carbon content in the range 0.05–0.25 wt.% can remain. The researchers are said to be working on modes of heat treatment for removing retained carbon and also additives to the feedstock granulate such as isopropyl alcohol, which should protect the permanent magnet compacts against oxidation during MIM processing. The stages of injection of the feedstock and the orientation of the magnetic particles by an external magnetic field are carried out simultaneously in a specially designed press mould. The Spetsmagnit company is reported to be producing permanent magnets by MIM which meet the property requirements of the Russian GOST 21559–76 standard.

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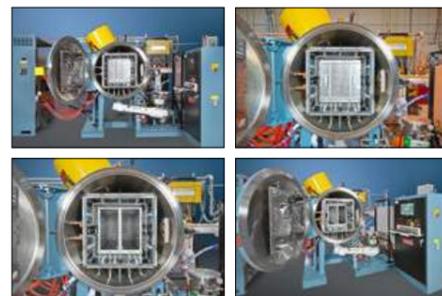


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Tensile toughening of MIM β Ti-Nb-Zr biomaterials by adjusting TiC distribution

Metal Injection Moulding has significant application potential as a cost-competitive process to produce β Ti-Nb-Zr biomaterials, for applications such as orthopaedic implants with complex shapes and high performance requirements. However, most β Ti-Nb-Zr alloys produced by MIM to date, or even by conventional Powder Metallurgy, have suffered from embrittlement induced by carbon contamination which originates from the debinding process, sintering atmosphere and starting β Ti-alloy powders. In particular, the MIM process uses polymeric binders, and extra carbon uptake commonly takes place during debinding where improper

Samples	Carbon (wt.%)	Oxygen (wt.%)	Nitrogen (wt.%)	TiC _x (fraction /%)
TZN20	0.047 ± 0.003	0.265 ± 0.001	0.082 ± 0.003	0.53 ± 0.05
TZN20-CSRA ^(a)	0.049 ± 0.002	0.258 ± 0.004	0.085 ± 0.005	0.51 ± 0.04
TZN20-Y ^(b)	0.053 ± 0.005	0.249 ± 0.010	0.076 ± 0.007	0.48 ± 0.10
TZN20-Y&CSRA ^(c)	0.043 ± 0.002	0.245 ± 0.006	0.050 ± 0.006	0.50 ± 0.09
TZN18-Y ^(b)	0.043 ± 0.011	0.275 ± 0.003	0.076 ± 0.002	0.25 ± 0.05
TZN18-Y&CSRA ^(c)	0.042 ± 0.003	0.279 ± 0.004	0.079 ± 0.002	0.24 ± 0.08

^(a)CSRA has an extra sintering cycle step, which was programmed after the conventional sintering cycle

^(b)0.1 wt.% yttrium powder was added into the metallic powder mixture

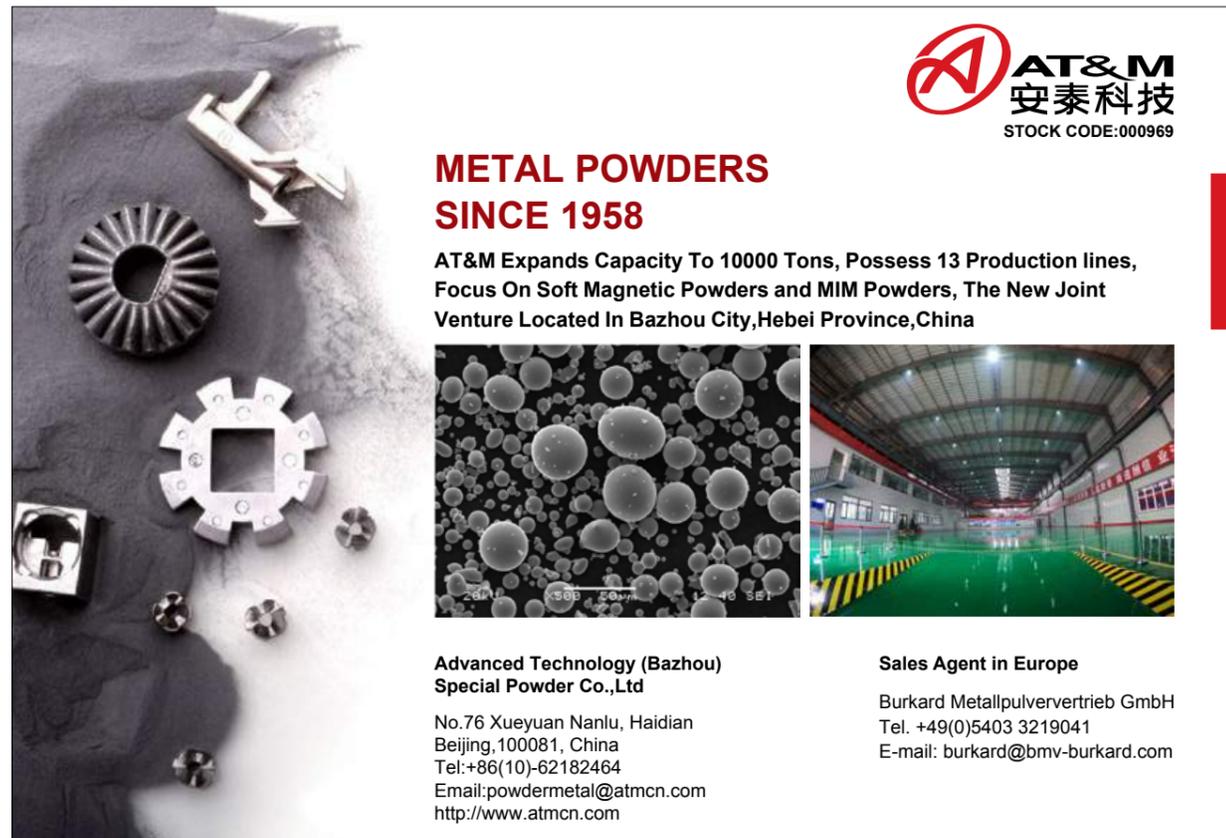
^(c)Both CSRA and Y processes were carried out

Table 1 Impurity levels and TiC_x volume fraction of as-sintered and CSRAed MIM-TZN alloys (From the paper 'Tensile toughening of Powder Injection Molded β Ti-Nb-Zr biomaterials by adjusting TiC particle distribution from aligned to dispersed pattern,' Peng Xu, Florian Pyczak, Ming Yan, Wolfgang Limberg, Regine Willumeit-Römer, Thomas Ebel, Applied Materials Today, Vol. 19 (2020))

removal of residuals after pyrolysis of polymers can often occur.

This issue has hindered the commercialisation of MIM β Ti-alloys

in structural bio-tolerant orthopaedic applications. Research conducted at the Institute of Materials Research, Helmholtz-Zentrum Geesthacht,





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Germany, and the Southern University of Science and Technology, Shenzhen, China, has focused on using the MIM process to produce bio-tolerant metastable β Ti-Nb-Zr alloys containing 0.05 wt.% standard carbon residual, and consequently 0.5 vol.% in situ synthesised TiC_x particles. The results of the research were recently published in a paper titled 'Tensile toughening of Powder Injection Molded β Ti-Nb-Zr biomaterials by adjusting TiC particle distribution from aligned to dispersed pattern,' by Peng Xu, Florian Pyczak, Ming Yan, Wolfgang Limberg, Regine Willumeit-Römer and Thomas Ebel in Applied Materials Today, Vol. 19 (2020).

The authors stated that their aim was to explore TiC_x redistribution methods via the generation of dispersed intergranular TiC_x to replace aligned GB-TiC_x in PM/MIM β Ti-Nb-Zr alloys. This would involve the systematic investigation of the mechanisms of the TiC_x redistribution induced by yttrium (Y) and carbide spheroidisation reprecipitation annealing (CSRA) on TiC_x precipitation.

The authors stated that Y specifically works as a 'moderator', which reduces the mean diffusion rate of carbon atoms by lowering the starting temperature of TiC precipitation, and that CSRA offers sufficient time to break Ti-C bonds and to lead originally acicular α -phases to form α -laths. These α -laths provide a great number of effective lattice-vacancies, and carbon atoms can diffuse and dissolve into these α -laths. The α -laths also keep carbon in dissolution until rather low temperatures, when TiC_x then precipitates near these α -laths or their bundles. The aligned-agglomerated GB-TiC_x particles are thereby adjusted to evenly-dispersed intragranular TiC_x, thereby toughening MIM-processed β Ti-Nb-Zr alloys by mitigating negative crack propagation modes. The authors believe that this approach is a better solution for the GB-TiC_x embrittlement of MIM β Ti-alloys than taking rigorous

Sample type	Conditions	TZN20 (wt.%)	TZN20-Y (wt.%)
i) Starting materials	unsintered	0.007 ± 0.001	0.007 ± 0.001
ii) Pressed and sintered parts	binderless (\approx 10% sintered porosity)	0.070 ± 0.002	0.068 ± 0.004
iii) PIM-processed parts	binder-based (5-6% sintered porosity)	0.047 ± 0.003	0.053 ± 0.004

Table 2 Carbon residuals of PM/MIM TZN20(-Y) specimens under various conditions (From the paper 'Tensile toughening of Powder Injection Molded β Ti-Nb-Zr biomaterials by adjusting TiC particle distribution from aligned to dispersed pattern,' Peng Xu, Florian Pyczak, Ming Yan, Wolfgang Limberg, Regine Willumeit-Römer, Thomas Ebel, Applied Materials Today, Vol. 19 (2020))

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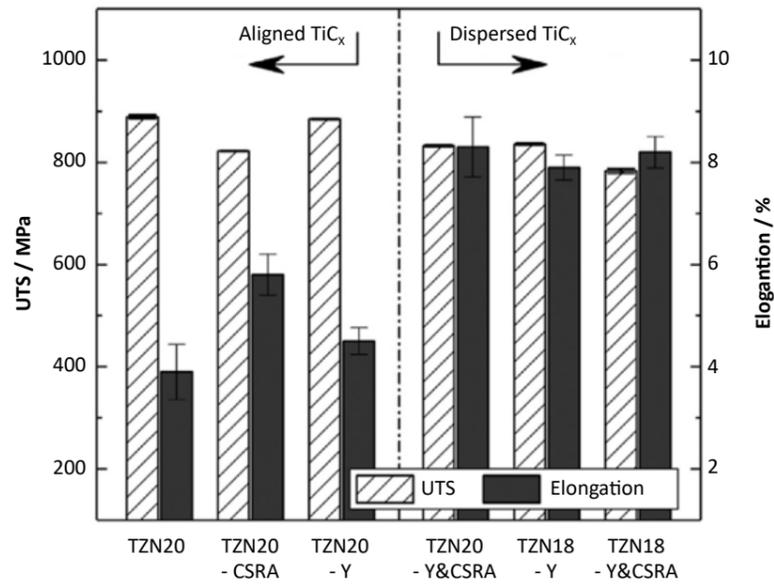


Fig. 1 Ultimate tensile strength (σ_{UTS}) and elongation to fracture (ϵ_f) of MIM-TZN alloys with different TiC_x particle distributional patterns (From the paper 'Tensile toughening of Powder Injection Molded β Ti-Nb-Zr biomaterials by adjusting TiC_x particle distribution from aligned to dispersed pattern,' Peng Xu, Florian Pyczak, Ming Yan, Wolfgang Limberg, Regine Willumeit-Römer, Thomas Ebel, Applied Materials Today, Vol. 19 (2020)

technical precautions against carbon contamination and TiC_x formation by proper adjustment of TiC_x phases spatial distribution.

Research into the MIM-produced β Ti alloys involved Ti-10Zr-20Nb (TZN20), Ti-10Zr-20Nb-0.1Y (TZN20-Y) and Ti-10Zr-18Nb-0.1T (TZN18-Y) alloys. The starting powders include titanium powder, which is spherical with a $< 45 \mu m$ particle size; a spherical master-alloy Ti-42Nb powder with a $< 63 \mu m$ particle size, selected to support homogeneous sintering compared with elemental powder; and both elemental Zr and Y powders of irregular shape with a $< 45 \mu m$ particle size.

The metal powder mixtures were blended with a polymeric binder made up of polyethylene-co-vinyl acetate, paraffin wax and stearic acid with powder loading at 65 vol.%. The granulate MIM feedstock was injection moulded at 1300 bar to produce standard tensile test specimens and debinding was done first under

Samples	σ_{YS} (MPa)	σ_{UTS} (MPa)	Elongation (ϵ_f) (%)	E-Modulus (GPa)	Grain size (μm)	Porosity (%)
TZN20	768 \pm 3.9	889 \pm 3.9	3.9 \pm 0.5	70.9 \pm 2.9	373 \pm 12	5.0
TZN20-CSRA	704 \pm 1.6	822 \pm 1.0	5.8 \pm 0.4	75.3 \pm 3.3	384 \pm 16	5.0
TZN20-Y	779 \pm 0.9	885 \pm 1.2	4.5 \pm 0.3	68.5 \pm 2.4	301 \pm 19	6.0
TZN20-Y&CSRA	742 \pm 4.1	832 \pm 2.1	8.3 \pm 0.6	65.7 \pm 4.6	317 \pm 15	6.0
TZN18-Y	708 \pm 3.3	836 \pm 2.2	7.9 \pm 0.2	78.4 \pm 1.2	325 \pm 5	5.5
TZN18-Y&CSRA	681 \pm 4.6	783 \pm 4.8	8.2 \pm 0.3	76.9 \pm 5.7	340 \pm 21	5.5

Table 3 Tensile and microstructural properties of MIM-TZN alloys at room temperature (From the paper 'Tensile toughening of Powder Injection Molded β Ti-Nb-Zr biomaterials by adjusting TiC_x particle distribution from aligned to dispersed pattern,' Peng Xu, Florian Pyczak, Ming Yan, Wolfgang Limberg, Regine Willumeit-Römer, Thomas Ebel, Applied Materials Today, Vol. 19 (2020)

hexane to remove the paraffin wax followed by thermal debinding, a conventional sintering cycle (1500°C for 4 h under vacuum with controlled cooling rate of 10 K/min) and additionally a newly-designed extra sintering cycle, i.e. carbide spheroidisation reprecipitation annealing (CSRA). The latter was carried out at 800°C for 1 h under vacuum with 10 K/min heating rate and 2 K/min cooling. To ensure compatible carbon uptakes for all specimens, the CSRA cycle was done separately from the sintering cycle. The authors also produced pressed and sintered binderless samples from the same MIM-TZN alloys for comparison.

Table 1 gives the as-sintered and CSRAed MIM-TZN alloys and Table 2 compares the extent to which the starting powders, debinding process and sintering contributed to carbon contamination. It can be seen that the final carbon residuals in

binderless press and sintered parts were, unusually, higher than in the MIM parts, which used binders. The authors reported that residual oxygen was also in-line with this tendency at ≈ 0.32 wt.%, an extra 0.05 wt.% O.

The authors stated that the tensile toughness behaviour of MIM-TZN alloys with aligned and dispersed TiC_x particle distributional patterns was found to be significantly different, as can be seen in Fig. 1 and Table 3. MIM parts with fully and partially aligned TiC_x particles showed relatively low elongation to fracture (Fig. 1, left), whereas the materials with dispersed TiC_x particles provided values for ϵ_f as high as 8% (Fig. 1, right). Additionally, elongation in TZN20 series was significantly improved after performing CSRA, but not much by only Y addition. The authors reported that a striking enhancement of $\approx 113\%$ in elongation was attained from conventional

sintered TZN20 to particle-redistributed TZN20-Y&CSRA. The ultimate tensile strength (UTS) values, as shown in Table 3, were found to decline marginally by CSRA in all conditions, probably due to the combination of slight stress relieving and microstructural change, whilst UTS was virtually unchanged by the addition Y. The authors concluded that the novel strategy developed to adjust particle distribution pattern (TiC_x phases redistribution) by regulating the precipitation evolution of TiC_x and eliminating aligned TiC_x particles can be an effective way to toughen PM and MIM β Ti-alloys, which suffer from embrittlement induced by carbon contamination.

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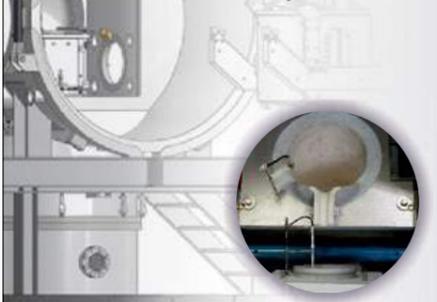
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Review of surgical tools and medical devices produced by Metal Injection Moulding published

Metal Injection Moulding has, over the past thirty years, achieved considerable success in the production of intricate components for a broad range of surgical devices, orthopaedic implants and other biomedical products made from a variety of biocompatible metal powders. A comprehensive review of MIM technology in the medical sector by A Dehghan-Manshadi, P Yu, M Dargusch, D StJohn, and M Qian, has been published in *Powder Technology*, Vol. 364, [2020], pp 189–204.

The review begins by providing an overview of MIM technology, such as feedstock preparation, injection moulding, debinding and sintering. This is followed by the latest trends for different metallic biomaterials processed by MIM, including stainless steels, titanium alloys, cobalt-chrome, iron and magnesium alloys, and the development of a selection of applications.

Just one of the many examples given by the authors is an intricate biomedical MIM part, which is used in a bone tissue engineering scaffold made to mimic the porous and permeable hierarchical architecture of the human bone and also to provide tissue support in-vivo through the porous MIM titanium structure. Such artificial bone scaffolds can be produced by MIM using a temporary space holder to achieve controlled porosity fraction and high pore interconnectivity.

The authors state that, thanks to their high sintered density, most MIM-produced biomaterials have static properties comparable to those made by conventional processes such as casting and forging. MIM has therefore found a number of applications in medical tools and instrument components, including minimally invasive

surgery (MIS) tools having ever more complex shapes such as laparoscopic and endoscopic jaws, graspers, scissors, cutting and suturing tools. They state that, in many cases, manufacturing of such geometrically complex tools is no longer possible with conventional technologies, and MIM provides an important, if not the only, affordable pathway to their production. Such MIM parts are usually made from different grades of stainless steels to provide the required strength, hardness, corrosion resistance and ease of sterilisation. MIM is also used to produce general surgical tools such as scalpel handles, nippers, forceps and parts for instruments. As a further example, numerous surgical forceps are successfully produced by MIM and feature many fine structures that would be difficult to manufacture by other methods.

Other groups of medical components which can be made by MIM are the trauma plates, blades, screws and fixation devices used for fracture fixation in orthopaedic surgery, orthodontics, drug delivery equipment, hearing aid components and stent implants. Currently, stents of different materials can be made by MIM, including stainless steel and NiTi alloys, with both materials providing good biocompatibility and the required mechanical properties.

The area of orthodontics, such as extremely small and precision MIM stainless steel and Ti alloy brackets and hooks, was one of the early success stories for the MIM industry and these remain leading MIM products for the dental sector. Also, in the dental industry, MIM is used to produce ultrasonic endodontic and scaler tips from 316L stainless steel powders. However, whilst several studies have confirmed the potential for the MIM process to

produce complex dental implants with micro details from stainless steel, titanium and magnesium alloys, the report states that mechanical property requirements have not always been met.

The same applies to other implants, which are subject to cyclic loading during their lifetime in the human body. Most MIM-produced biomaterials have static properties comparable to those produced by casting or forging, but their dynamic properties, especially fatigue strength, may be lower should small pores be present in the as-sintered microstructure. These pores can, of course, be eliminated by adding a Hot Isostatic Pressing (HIP) step after sintering to significantly improve fatigue properties. The authors stated that, whilst the use of MIM technology to produce medical implants is still largely under development, the future demand for implants with geometrically

complex shapes significant progress in optimising the MIM process, and improved availability of powder materials such as fine spherical Ti alloy powders, is expected to result in more implants being produced by MIM.

The authors stated that the corrosion performance of MIM-produced biomaterials is still an area that needs further research. Systematic experimental data are still missing on the in-vitro and in-vivo corrosion performance of MIM fabricated implants and are needed to optimise the different aspects of the MIM process. This includes the development of fully biocompatible binder systems, optimum powder size and distribution, debinding conditions and sintering cycles. MIM technology has also shown potential to produce porous metal implants and the technology can be used as a cost-effective

solution for the production of novel designs, including micro-sized and functionally graded devices, which may provide new pathways and solutions to current healthcare problems.

The authors concluded that the continuous healthy development of metal Additive Manufacturing (AM) is expected to further drive down the cost of the type of metal powders used by both MIM and AM industries. It is also concluded that the possibility of producing intricate and multifunctional injection moulding dies by AM for use in Metal Injection Moulding, plus lower powder prices, could lead to more affordable MIM parts.

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Oxygen content control in MIM of water atomised 316L stainless steel powders

Austenitic 316L stainless steel is one of the most important materials used in the Metal Injection Moulding industry to produce components with excellent properties such as ductility, high corrosion resistance and good surface finish. Both gas atomised (GA) and water atomised (WA) 316L stainless steel powders are used in MIM production, with the water atomised powder reported to have the advantage of lower cost due to the higher yield of fine powders produced by the water atomisation process compared with gas atomisation. However, the oxygen content of water atomised 316L stainless steel powder, at 3000 to 5000 ppm, is significantly higher than that of the gas atomised grade, which is usually less than 1000 ppm. This higher oxygen content adversely affects the sintering of MIM 316L stainless compacts leading to decreased density and lower mechanical properties of the sintered parts. In addition, the higher oxygen content also has an adverse effect on the corrosion resistance of sintered stainless steel.

Researchers at the Southern University of Science and Technology, Shenzhen, China, and the University of Macau, Taipa, Macau, China, have been investigating the development of technology which can effectively control the oxygen content in 316L stainless steel MIM parts produced from WA powders using low cost graphite additions. Kaiping Yu and colleagues described the results of their work in a paper: 'Oxygen content control in MIM 316L austenitic stainless steel using water atomized powder', published in the *Journal of Manufacturing Processes*, Vol. 50, (2020), pp 498–509.

The authors used fine particle size water atomised 316L stainless powder produced at the Guanzhou Research Institute for Non-ferrous Metals, with the morphology shown in Fig. 1. The powder, which has an oxygen content of ~4200 ppm, was mixed with a POM-based binder containing 86 wt.% polyformaldehyde, 8 wt.% high-density polyethylene (HDPE), 4 wt.% ethylene-vinyl acetate copolymer (EVA) and 2 wt.% stearic acid (SA). Powder loading in the binder system was fixed at 63 vol.%. To produce the MIM feedstock, the POM-based binder was first heated to 190°C, which was high enough for all binder constituents to melt. The stainless steel powder and the small amounts of graphite powder (0, 500, 1000, 1500 and 2000 ppm) were then added for mixing with the melted binders. Mixing of the feedstock was carried out using a torque rheometer equipped with a kneading unit and mixing was completed after kneading for 30 min.

Green tensile test bars were moulded using a mini injection moulding machine and the green test bars were debound in a catalytic debinding furnace to remove the POM binder. The rest of the binders were thermally removed in a vacuum furnace and the parts were sintered in the same furnace at 1350°C for 2 h under a flowing argon atmosphere. Table 1 summarises the oxygen and carbon contents and graphite dosages,

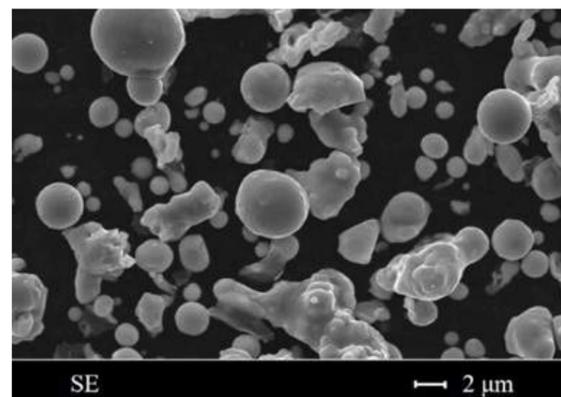


Fig. 1 SEM micrograph showing the morphology of the water atomised 316L stainless steel powder (From paper: 'Oxygen content control in MIM 316L austenitic stainless steel using water atomized powder', by Kaiping Yu et al, *Journal of Manufacturing Processes*, Vol. 50, (2020), pp 498–509)

	A	B	C	D	E
Graphite dosage (ppm)	0	500	1000	1500	2000
Oxygen content (ppm)	1533 ± 111	849 ± 16	444 ± 23	0	0
Carbon content (ppm)	0	0	0	155 ± 2	670 ± 16
Average grain size (µm)	43.0	42.4	36.8	51.8	97.0
Lattice parameter (Å)	3.5925	3.5952	3.5966	3.5973	3.5994
Density (g/cm ³)	7.837 ± 0.005	7.863 ± 0.005	7.897 ± 0.005	7.873 ± 0.005	7.64
Relative Density (%)	98.21 ± 0.06	98.53 ± 0.06	98.96 ± 0.06	98.66 ± 0.06	95.7
Yielding Strength (MPa)	185 ± 3	172 ± 1	174 ± 2	172 ± 2	203 ± 3
Ultimate Tensile Strength (MPa)	528 ± 2	522 ± 2	522 ± 2	527 ± 2	548 ± 6
Elongation (%)	66.1 ± 1.4	70.1 ± 0.9	72.9 ± 0.4	76.5 ± 0.8	56.3 ± 1.9
I _{corr} (nA/cm ²)	7.81	10.1	10.2	5.79	6.29
E _{corr} (mV)	-13.7	-14.2	-21.8	-29.6	-36.0
Epit (mV)	330	354	411	256	119

Table 1 Summary of chemical compositions, sintered densities, mechanical properties and electrochemical test results of the sintered 316L stainless steel samples with different graphite dosages (From paper: 'Oxygen content control in MIM 316L austenitic stainless steel using water atomized powder', by Kaiping Yu et al, *Journal of Manufacturing Processes*, Vol. 50, (2020), pp 498-509)

sintered densities, mechanical properties, and electrochemical test results of the sintered MIM 316L stainless samples. The samples doped with 0, 500, 1000, 1500 and 2000 ppm graphite are designated as samples A, B, C, D, and E, respectively. Fig. 2 shows their oxygen and carbon contents after sintering based on graphite dosages. The results show that the addition of graphite efficiently reduces the oxygen content in the sintered 316L stainless steel.

As can be seen, the sintered density increases to a peak value of 7.90 g/cm³ with a corresponding graphite dosage of 1000 ppm (sample C). However, a further increase in graphite dosage causes an adverse effect on the sintered density because excessive carbon remains in the sample and this has an even more significant effect on the sintered density than oxygen. For example, when more graphite is added, the sample becomes overdosed with carbon and the excessive carbon remains in the sintered samples, forming carbon-rich Cr-depleted particles with Fe and Cr, which proves

very detrimental to the ductility and corrosion resistance of the material. Graphite dosage of 2000 ppm results in 670 ppm excessive carbon in the sintered samples, reducing density to

7.64 g/cm³, ductility down to 56% and pitting potential down to 119 mV.

The authors found that, in this research, the oxygen content of the starting water atomised 316L

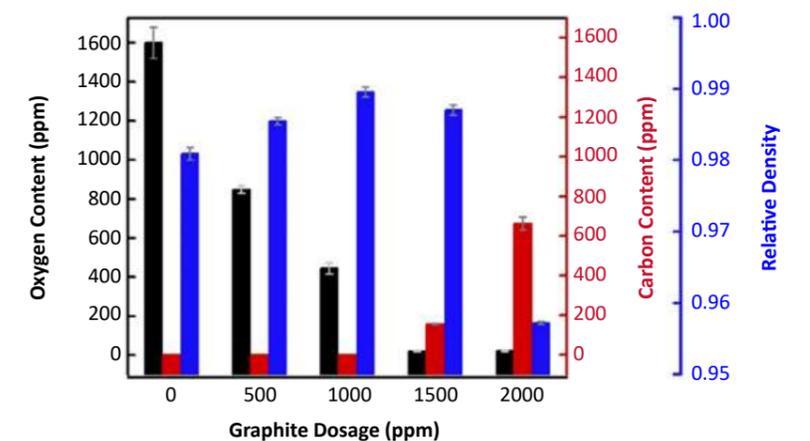


Fig. 2 Influence of oxygen/carbon contents on sintered density of the sintered 316L stainless steel samples with different graphite dosages (From paper: 'Oxygen content control in MIM 316L austenitic stainless steel using water atomized powder', by Kaiping Yu et al, *Journal of Manufacturing Processes*, Vol. 50, (2020), pp 498-509)

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powder at ~4200 ppm is high enough not only to negatively influence the solidification process during sintering, but also to deteriorate the mechanical and corrosion properties of the sintered material. This high oxygen content can be reduced to around 1553 ppm through carbon generated by the binders, but this alone is insufficient to reduce all oxygen during the sintering, as shown in sample A. However, the authors found that, when graphite is deliberately added as an extra carbon source, this can be an effective method to further

bring down the oxygen content, because the two elements cancel each other out during sintering. Based on the experimental results, the authors have developed an empirical formula, which can be used to predict the contents of remnant oxygen and carbon in the sintered MIM 316L stainless steel samples.

All the sintered MIM 316L stainless steel samples were found to have uniaxial grains featuring twin structures, which are typical of austenitic stainless steels. However, the addition of graphite was also

found to have a significant influence on the grain size of the austenite in the sintered samples. Fig. 3 shows EBSD images of the sintered MIM 316L samples. The authors stated that the average grain size for the sample without any graphite addition is around 37 µm and it changes little with graphite dosage up to 1000 ppm. However, with additions of graphite greater than 1500 ppm, grain size increases and reaches 93 µm when 2000 ppm of graphite is added.

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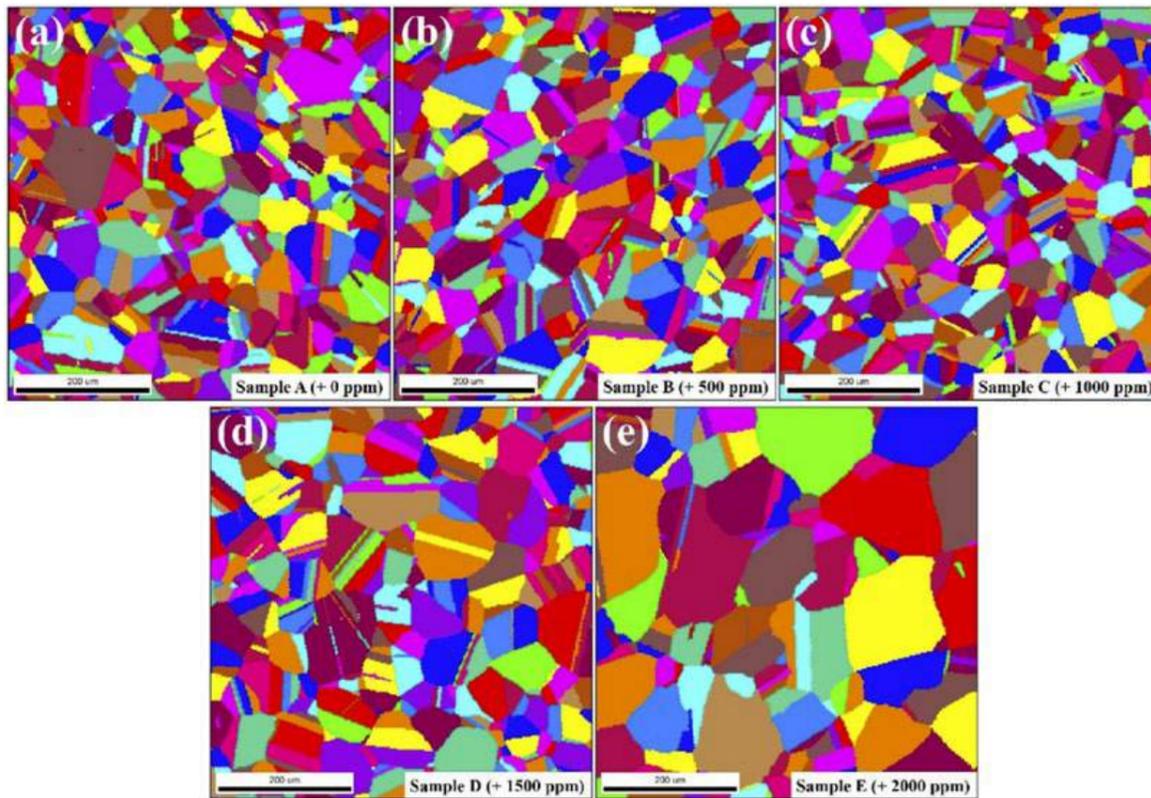


Fig. 3 EBSD images showing the grain sizes of sintered 316L stainless steel parts doped with (a) 0 ppm, (b) 500 ppm, (c) 1000 ppm, (d) 1500 ppm and (e) 2000 ppm graphite [From paper: 'Oxygen content control in MIM 316L austenitic stainless steel using water atomized powder', by Kaiping Yu, et al, *Journal of Manufacturing Processes*, Vol. 50, (2020), pp 498-509]



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Element 22: A leader in titanium MIM leverages its expertise to advance sinter-based Ti Additive Manufacturing

The production of titanium components by powder-based processes requires specialist knowledge and in-depth expertise in the handling and, in particular, the debinding and sintering of this highly reactive metal. Element 22 GmbH is a global leader in the Metal Injection Moulding of titanium and its alloys, and a growing focus of the company's development activities is sinter-based Additive Manufacturing. Dr Georg Schlieper visited the company on behalf of *PIM International* and reports on the current state of production and the company's future ambitions.

Based in the city of Kiel, in the German province of Schleswig-Holstein and on the shores of the Baltic Sea, visitors approaching Element 22 GmbH are greeted by the screeching of seagulls from the neighbouring fishing port. The company, located in an innovation centre on the site of an old fish market, is a world leader in the production of pure titanium and titanium alloy parts by powder metallurgical processes.

With a workforce of approximately fifty, the company processes roughly twenty-five tons of titanium components a year. From 2014 to 2020, production capacity was increased in several stages to seventy-five tons a year, so there is extra capacity for future growth. The facility's production area covers some 1,200 m², whilst a further 500 m² is dedicated to management, administration and commercial offices.

The technological fundamentals of titanium sintering were a focus of efforts at Fraunhofer IFAM in Bremen and Helmholtz-Zentrum in

Geesthacht in the late 1990s. After the first attempt to introduce this technology for medical applications by TiJet Medizintechnik GmbH, also based in Kiel, failed to succeed, the assets of TiJet were taken over by Element 22 in 2011.

Matthias Scharvogel, founder and CEO, Element 22, explained to *PIM International* that the company's early years were dedicated to closing technological gaps so as to master the technology for the MIM of titanium and its alloys safely



Fig. 1 A Ti6Al4V MIM sleeve with anodised surface coatings (Courtesy Element 22)



Fig. 2 Equipment for solvent binder removal and solvent reprocessing via distillation at Element 22

and in high-volume production environments. An important step forward was made in 2012, when the company's first MIM Ti implant received approval from the US Food and Drug Administration (FDA). Further approvals and certifications for the medical and aerospace industries followed.

Maintaining close relationships with research institutions, both regionally and further afield, has been an integral part of the company's philosophy since its beginnings. Many of its young technicians and engineers undertook research work at Element 22 as part of their education; the practice of hiring these graduates continues to this day, allowing both student and potential future employer to get to know each other over a longer period of time.

Students who are studying for a technical degree, who fit in well with the company and are seeking a job, will be offered permanent employment after completing their

studies. Wendelin Winkelmüller, Element 22's CTO, believes that while titanium powder metallurgical manufacturing has come a long way, there is still room for improvement and the subject is so complex that there is plenty of material on which students can write future studies and theses.

The MIM process used by Element 22 is based on several proprietary binder systems. Feedstock is prepared in-house in two heated kneaders. Four fully-electric injection moulding machines, with clamping forces ranging from 300–800 kN, are available. Depending on the size of parts and the quantities required, tooling with one-to-six mould cavities is used, often in combination with hot runner technology in order to avoid the regrainulation of runners.

Automation is an important topic for process engineering and at Element 22 the target is to run injection moulding machines

fully automatically in a three-shift operation, removing green parts from the moulds using pick-and-place robots and placing them on trays for debinding and subsequent sintering. For many parts, this level of automation has already been realised.

The debinding and sintering process starts with solvent debinding of the main binder constituent, and three tanks are available for this process. The solvent, which is contaminated with the binder after debinding, undergoes an integrated distillation process and is subsequently recycled (Fig. 2).

The debinding process is followed by thermal removal of the backbone binder and sintering in a vacuum furnace (Fig. 3). While the appearance of the parts leaving the sintering furnace can be adjusted by sintering profile, for many applications a secondary operation is undertaken in order to improve the surface quality. Shot peening with sand or glass beads and polishing are often used to optimise surface appearance. Other secondary processes, such as Hot Isostatic Pressing (HIP), CNC machining and hard or colour anodising, are outsourced to external suppliers.

In 2018, Element 22 entered a joint venture with MUT Advanced Heating GmbH, a specialist in vacuum debinding and sintering furnaces based in Jena, Germany. The jointly-formed company, Titanium Generation GmbH (TiGen), offers equipment and engineering support for the production of titanium and other reactive metals by both MIM and Additive Manufacturing.

In addition, TiGen offers complete solutions for the setting up and commissioning of equipment, as well as technical support for the required peripherals. The formation of this joint venture is a reflection of how firmly both companies, MUT and Element 22, believe in the potential for components made from titanium powder.



Fig. 3 Vacuum sintering furnaces installed at Element 22

Element 22's Selected Bead Sintering (SBS) process

Element 22 has developed a patented technology for sintering titanium products: Selected Bead Sintering. This technology allows Ti6Al4V to be sintered to a density of at least 99.5% at temperatures below 1100°C, whereas the usual sintering temperature for this alloy is about 1300°C.

This significant drop in sintering temperature is made possible by two factors. Firstly, a very fine Ti6Al4V powder with a maximum particle size of less than 25 µm is used as the raw material. Thanks to its large specific surface area, this extremely fine powder enhances the diffusion processes during solid state sintering; as powder metallurgists would say, it had 'a high sintering activity'. Secondly, this alloy can be sintered in the high alpha-beta phase region.

Self-diffusion in the body-centred cubic lattice of the beta phase occurs many times faster than in the hexagonal close-packed alpha modification. As a consequence, sintering in the two-phase region is particularly suitable to achieve a fine microstructure: a high beta phase fraction ensures efficient densification, while residual alpha grains prevent excessive beta grain growth.

By avoiding the grain growth that takes place at higher temperatures, the SBS process creates entirely new microstructures. As a result, the most widely used titanium alloy, Ti6Al4V, can be sintered to an extremely fine-grained microstructure (Fig. 4) that leads to higher strength and ductility than is available in wrought Ti6Al4V. The specific strength, i.e. Ultimate Tensile Strength (UTS) divided by the density, is a measure of the performance of materials. In a comparison of the specific strength of several materials, the SBS

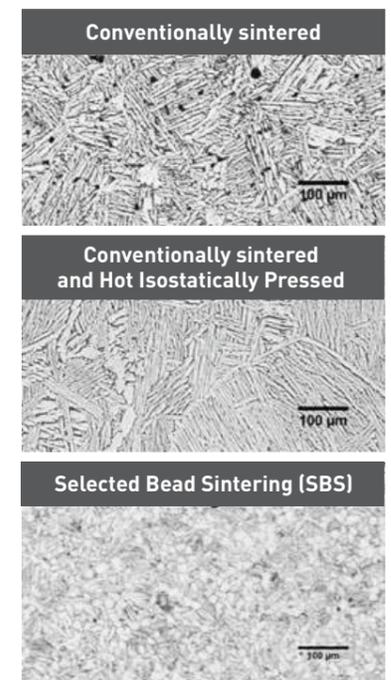


Fig. 4 A comparison of Ti6Al4V microstructures showing the fine grain structure that can be achieved with Element 22's SBS process

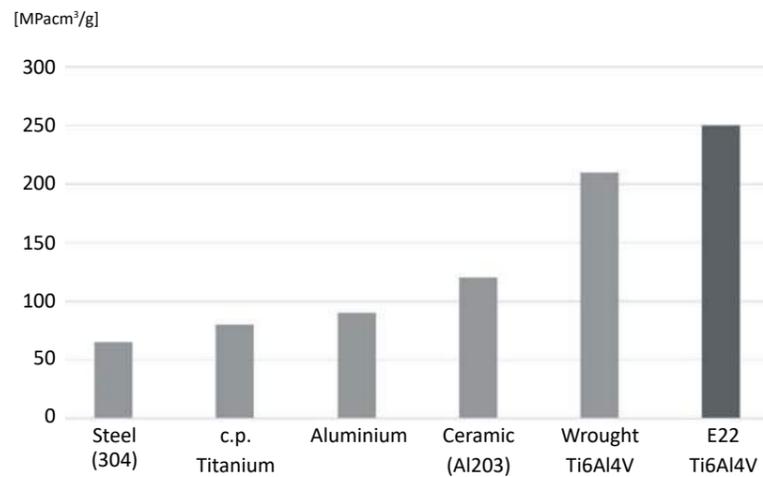


Fig. 5 The specific strengths of various materials compared with SBS Ti6Al4V



Fig. 6 A spinal implant produced by MIM at Element 22

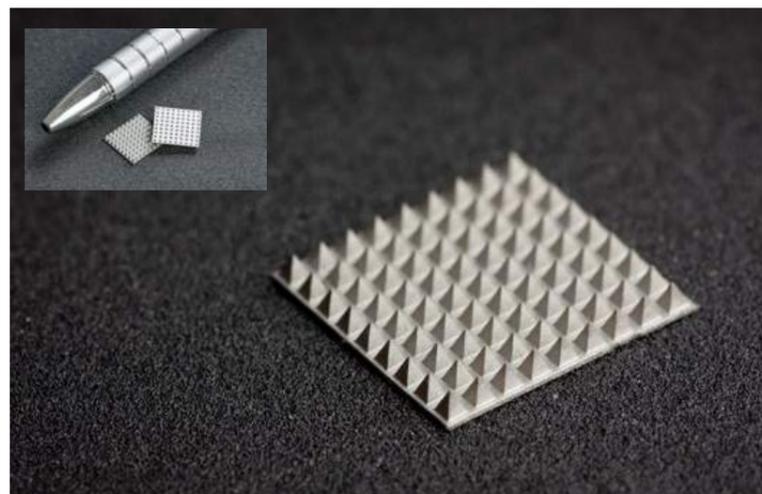


Fig. 7 A miniature MIM Ti6Al4V plate with eighty-one hollow pyramidal shapes, each with a wall thickness of 0.1 mm on each tip

sintered Ti6Al4V alloy stands out (Fig. 5). Not only does the material offer excellent static and dynamic mechanical properties as a result of its extremely fine microstructure that is practically free from residual porosity, but this is achieved without the need for post-processing by HIP. As a result, the process enables the production of components with a superior surface finish after sintering that can deliver unrivalled polishing results.

A particular challenge for the SBS process is the requirement for an oxygen content below 0.2%, according to ASTM F2885-17, which limits the choice of applicable binders and places high demands on the process technology. Fine powders have a very large specific surface area, which can react with oxygen in the atmosphere. One of many measures taken by Element 22 to meet this requirement is to handle the powder exclusively in glove boxes under a protective atmosphere. If the fine titanium powder were to be exposed to air, it would create several potential problems. Once the powder has been worked into the binder, however, it is protected against further oxidation.

For the debinding and sintering of the green parts, specialist knowledge is also required. Because of the high surface activity of the powder, the potential to pick up impurities is very high. In particular, oxygen, nitrogen and carbon contamination need to be avoided during this process step in order to achieve the required material properties.

Together with MUT Advanced Heating, Element 22 has optimised plant design and process parameters as well as process reliability for debinding and sintering. With these conditions, impurity pickup of the material is extremely low, enabling it to remain within the stringent requirements of the medical and aerospace industries; this is one element of the core knowledge required to produce high-quality titanium parts.



Fig. 8 Metal injection moulded cpTi screw with M2 thread used in implant applications

There are additional patents in the pipeline which, Scharvogel states, will allow the industry to continuously improve for many years to come. "It is these key technologies that demonstrate the technological leadership of Element 22 in the field of MIM titanium," he explains.

According to Scharvogel, Element 22 benefits from the fact that both the quality and the batch-to-batch consistency of titanium powders, as well as the number of suppliers, have risen sharply in recent years. As a result, the supply of high-quality powders is more than adequate and prices are more competitive than in the past. The main driving force behind this increase in supply and quality, of course, wasn't the MIM industry, but the fast-growing demand for Ti powders for AM. It is also a major advantage for MIM that the fine powder fraction below 25 µm that is required for MIM processing is smaller than the fractions required for Laser Beam (LB-PBF) and Electron Beam (EB-PBF) Powder Bed Fusion (PBF) AM.

Current markets for titanium MIM

Element 22 is a global technology leader in the powder metallurgical processing of titanium and its alloys, as well as a leader in production capacity for sintered titanium components. The main markets served by

shown in Fig. 6. The remaining 25% of production is shared by aviation and consumer products.

The range of part sizes produced by Element 22 is extraordinarily wide. A large portion of the company's products are in the micro-MIM range; it is capable of producing parts with less than 0.1 mm wall thickness and the smallest parts

"A large portion of the company's products are in the micro-MIM range; it is capable of producing parts with less than 0.1 mm wall thickness and the smallest parts weigh only 5 mg..."

the company today are the medical, aerospace and high-end consumer industries. Of these three pillars, medical technology is currently the strongest, accounting for around 75% of the company's total output. A representative example of this field of applications is the spinal implant,

weigh only 5 mg. The possibilities for the production of extremely thin-walled MIM parts with detailed contours are demonstrated by the platelet with eighty-one pyramidal shapes shown in Fig. 7. Fig. 8 shows a tiny screw with an M2 thread. Both parts are manufactured to net

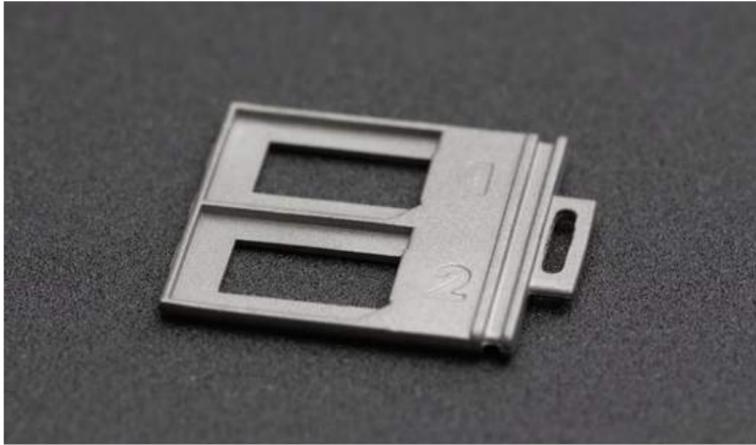


Fig. 9 Titanium MIM double SIM card holder



Fig. 10 A MIM Ti6Al4V surgical handle, weighing 80 g [Courtesy Bluewater Medical]

shape, with no secondary operations required.

An example from the consumer goods sector is the double SIM card holder for a mobile phone shown in Fig. 9. A much larger part is a handle used for orthopaedic surgery, which weighs approximately 80 g (Fig. 10). The largest MIM part produced by Element 22 is a fixture for an aircraft engine, approximately 120 mm in length and 143 g in weight.

The dimensional tolerances of titanium MIM parts after sintering are similar to those of ferrous MIM. The rule of thumb given by Element 22 and many other manufacturers of MIM parts is +/- 0.3% of the nominal dimension. Details regarding critical dimensional tolerances have to be agreed with each customer.

Target applications and market overview

Despite Element 22's leading position as a MIM titanium part supplier to the medical, consumer and aerospace sectors, Scharvogel has a focus on future areas of opportunity. The medical sector is currently the most important to Element 22, consuming a large proportion of its production in the form of thin-walled housings for implantable devices, reinforcement and fastening elements for bones, dental implants, etc. However, Scharvogel estimates that in the future, this sector has the potential to account for around 20% of the total market for MIM titanium parts, as the new markets highlighted following adopt the technology.

Offshore and marine

Scharvogel believes Ti MIM has much to offer the offshore and marine sector. Thanks to their excellent resistance against seawater corrosion, titanium components are already finding application in marine environments such as offshore platforms, in the standing rigging of sailing yachts, in diving knives, in sea water desalination plants and more. He believes these applications could amount to 5% of the Ti MIM market.

Automotive

The automotive industry is increasingly using titanium components to save weight. Due to its relatively high cost, titanium is mainly used in high-end vehicles, but it is gradually becoming popular in mid-size cars as well. The lightweighting of components through the use of materials such as titanium is a particularly effective means of saving fuel in applications with rotating or alternating movements such as connecting rods, engine valves, rocker arms, turbochargers, etc. Scharvogel believes MIM titanium parts can probably reach a 10% market share in this field.

Consumer goods

Consumer goods are an important and unique field of application for titanium. The attractive appearance and biocompatibility of titanium are beneficial in consumer products such as wristwatches and bracelets, spectacle frame parts and many more. The material's light weight, corrosion resistance and high strength-to-weight ratio also make titanium attractive for many sports and outdoor applications, such as in high-end bicycle components, golf clubs, tennis rackets and mountaineering equipment. Many of these applications are well-suited to production by MIM. The market share of these products is estimated to be 25%.

Electronics

Some electronic goods also contain titanium parts, often for aesthetic reasons and for the material's

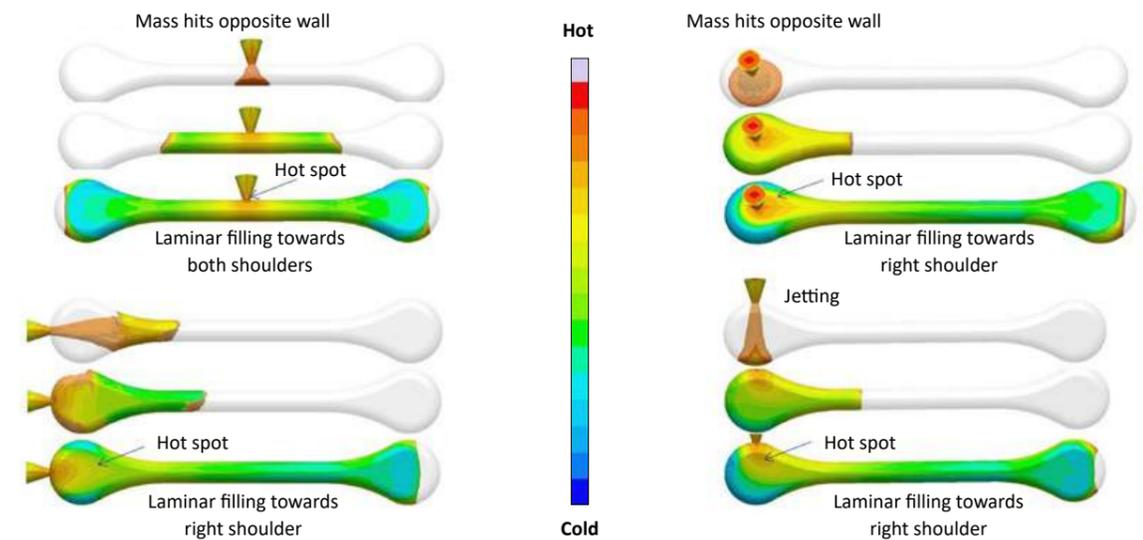


Fig. 11 Mould fill studies by computer simulation are helpful in tool design

low weight, strength and corrosion resistance. Scharvogel allocates a market potential of 10% to this sector.

Law enforcement and firearms

Military and police equipment also often contains lightweight components made of titanium. Examples include bulletproof vests, handcuffs with titanium locks and firearms. The market share may reach 10%.

Aerospace

In the past, the aerospace industry had great reservations about metal powder-based processes; sintered products were considered inferior and unreliable. This view has changed fundamentally with the advent of AM, because the benefits of AM for aerospace are so obvious that they outweigh past reservations. The overall attitude towards metal powder-based products has improved significantly since then. Today, the MIM industry benefits from this changed attitude. Scharvogel estimates a potential market share of 15% for MIM and sinter-based AM parts in the aerospace sector.

Chemical processing and hydrogen storage

Titanium is also used in many chemical processes and new applications around hydrogen storage, taking another 5% market share.

Innovations in the simulation of the MIM process

For several years, Element 22 has been working intensively on computer simulations of the processes it uses in-house. The four processing steps at Element 22 are:

- Feedstock preparation
- Injection moulding
- Solvent debinding
- Thermal debinding and sintering

In principle, individual MIM process steps influence each other and are all critical. However, feedstock preparation is a batch process that is consistent for each lot. The process complexity starts to increase significantly with the geometry-specific moulding step. The company therefore decided to concentrate

initially on the injection moulding step and leave feedstock preparation aside. In a second phase, the effects of thermal debinding and sintering have been investigated and solvent debinding, also a topic of great interest, will be tackled later.

The expectations for the computer simulation are manifold. When looking at injection moulding, it is sometimes possible to clarify at the enquiry stage, by means of a computer simulation, whether and in what way a component can be produced via MIM. This is particularly useful for parts with a very thin wall thickness, where a computer simulation can enable more precise statements about manufacturability than mere experience values. The number and positioning of the gates are also crucial for the injection moulding process and this is where computer simulation is the most advanced. Simulation also provides information about possible moulding problems such as jetting, hot spots, powder-binder segregation and weld lines (Fig. 11).

Element 22 has no in-house tool shop, but relies on external suppliers for tooling. Before an injection

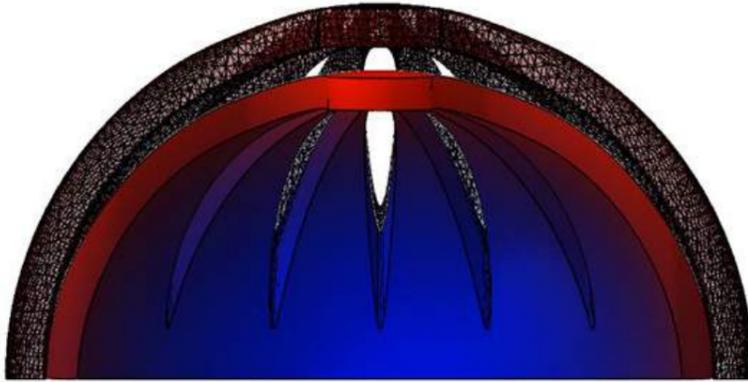


Fig. 12 Computer simulation of shrinkage and distortion of the demonstrator part, an acetabular cup, shown in Fig. 13

tooling is commissioned, computer simulation is regularly used to verify the design and to check what the temperature distribution will be in the tool. In this way, mould temperature control can be optimised.

Key to dimensional accuracy is the thermal debinding and sintering process. Element 22 has developed two approaches to predict shrinkage and distortion in metal injection moulded titanium parts. Both approaches are based on

such as residual stresses and inhomogeneities, cannot be considered by PhenoTi.

In order to take these effects into consideration, Element 22 has developed another, powder-based approach to simulate the sintering process: NumericTi. This tool is based on the common theory of solid-state sintering and uses the programming interface of the Multiphysics software to specify the material laws. An example

“Element 22 has developed two approaches to predict shrinkage and distortion in metal injection moulded titanium parts. Both approaches are based on commercially available Multiphysics software...”

commercially available Multiphysics software.

The first approach, PhenoTi, is a set of virtual material parameters for included functionalities of the Multiphysics software. PhenoTi can be used to predict geometry-induced dimensional change due to warpage and friction with the sinter plate of a perfect brown part. The influence of injection moulding-related effects,

of the computer simulation of dimensional change is given in Fig. 12. It shows the brown stage and the sintered stage of the semi-spherical demonstrator part shown in Fig. 13.

In addition to a suitable theory, a large amount of data and a quantitative knowledge of the material to be simulated is vital for accurate simulation results.

For this purpose, Element 22 had extensive material tests carried out at a German university to determine the necessary multidimensional dependencies of its material properties. Currently, the material data are tailored towards titanium and its alloys, but the same software can be applied to other metals as well, once a defined set of testing is carried out.

Max Tacke, a Process Development Engineer responsible for computer simulation at Element 22, stated that the foundation stone has been laid and he expects continuous progress in the future that will lead to the faster development of new products with fewer problems. “Our experience with computer simulation will also be very useful for Additive Manufacturing, the big topic of the future,” he stated.

Making the move towards sinter-based titanium Additive Manufacturing

In 2020, Element 22's R&D efforts are focused on the Additive Manufacturing of titanium. At present, the most intensive process development is taking place in the field of sinter-based AM. This is because the company's expertise in binder systems and the sintering of titanium alloys and other reactive metals is its particular strength. Existing equipment for debinding and sintering of MIM parts can also be used for sinter-based AM, which reduces the upfront investment required.

Matthias Scharvogel sees the AM of titanium powder as a perfect complement to MIM, not as a competing process. “We want MIM to continue to grow,” he says, “but there are geometries and required quantities where MIM is not the best choice and AM can do the job better.” He is convinced that titanium components made by sinter-based AM will find their market. If the required quantity of a product is not enough to justify the investment in MIM tooling, AM is often the solution. Furthermore, AM is able to generate



Fig. 13 An additively manufactured medical implant (acetabular cup) made of Ti6Al4V. The cup was manufactured by Headmade Materials using a novel sinter-based AM process that it calls Cold Metal Fusion. In this process, a PIM-like feedstock is processed in an LB-PBF system designed for polymer materials, before debinding and sintering – in this case by Element 22

prototypes in a short time at affordable cost, so the end-user can test the design of a new MIM product and modify it, if necessary, before investing in production tooling.

These technologies are being developed in close cooperation between Element 22 and AM machine and technology developers. Dr Johannes Schaper, AM Project Manager at Element 22, commented, “We are approached by the systems manufacturers rather than vice versa, as they are very much interested in benefitting from our processing expertise.”

Element 22 provides the necessary expertise for the required binder systems and post-build debinding and sintering processes. “It is important that the binder systems used are tailored towards the reactive metal and the actual machine and build process, but also for debinding and sintering in order to achieve good printing results and

good material properties,” explained Scharvogel.

Element 22 has not committed itself to a particular type of AM, but evaluates all sinter-based processes that exist today and may still emerge in the future, in order to get to know their strengths and weaknesses from a technical and economic point of view.

Material Extrusion

One approach of interest is Material Extrusion (MEX), also known as Fused Filament Fabrication (FFF) or Fused Deposition Modelling (FDM), which is widely used for plastic Additive Manufacturing as well as, less commonly, for metal. A great variety of low-cost desktop MEX machines is on sale, but many of these are not directly suitable for metal powder-based filaments. Some manufacturers, however, have developed AM machines precisely for the MEX of metal powder-filled filaments.

In MEX, a filament is heated and plasticised in a build head or ‘print head’ and the material is then deposited on a ground plate to build the product. Element 22 has developed a filament containing metal powder and a binder that is sufficiently flexible to enable it to be wrapped into a spool and processed on a desktop machine. The binder is similar to the one it uses for MIM, and debinding and sintering are carried out using the same equipment that is used for its MIM parts.

The company will, in due course, offer sintered AM components made using its technology and will also provide the filament to selected customers who wish to additively manufacture sinter-based titanium parts themselves. If a customer has no suitable equipment, Element 22 also plans to offer debinding and sintering services.

Binder Jetting

Binder Jetting (BJT) is currently the fastest AM process for building green components. How Element 22 manages issues around a powder bed of extremely fine, pyrophoric powder remains its secret; so far, however, the dimensional accuracy and surface quality of green titanium parts that it has additively manufactured by Binder Jetting is reported to be inferior to that achieved by other sinter-based processes. But, Element 22 feels confident that this challenge can be resolved and that excellent material properties can also be achieved.

Vat Photopolymerisation

Vat Photopolymerisation (VPP), also known as Stereolithography, has also been applied to titanium recently. In this process, the surface layer of a bed of photopolymer is selectively cured using ultraviolet (UV) light. When the surface layer has hardened, the build platform is lowered and the surface covered with fresh polymer; then the next layer is exposed, and so on.

To apply this process to titanium, the photopolymer typically used has been modified and highly loaded with metal powder. The viscosity of this slurry can be adjusted over the temperature of the powder bed and the part to be additively manufactured does not require any support structures. Green parts additively manufactured by VPP are subsequently processed by debinding and sintering in the same way as MIM parts. According to Schaper, this process yields a very high resolution, but the build rate is currently still relatively slow. More research is required before the process is ready for industrial production and the material is free from contamination.

Cold Metal Fusion

The Cold Metal Fusion process is another promising sinter-based AM approach. The process, developed by Headmade Materials GmbH, Würzburg, Germany, uses a standard LB-PBF system designed for polymer materials. Thanks to the relatively high build rates and low

investment costs, final part costs are relatively low. Element 22 is adapting this process in partnership with Headmade Materials for a number of commercial titanium applications (Fig. 13).

Screen printing

Screen printing has also been applied to sinter-based titanium part production. The adaptation of screen printing for metals uses a paste loaded with metal powder which is applied through a screen onto the build platform, building a component up layer by layer. The process is fast, low-cost, industrialised, and delivers a high resolution, but the shape of the component is defined by the screen only in the X and Y directions. Each change of shape in these directions requires a new screen. Therefore, the process is predominantly suitable for relatively simple geometries.

It is clear that all sinter-based AM processes for titanium and other reactive metals have their pros and cons and require further research before they are truly ready for industrial use. Element 22 is committed to contributing its share in bringing this technology forward. Ultimately, the task is to evaluate the strengths and weaknesses of the different process variants and decide which components can best be produced according to which process.

AM and COVID-19

The outbreak of the coronavirus (COVID-19) pandemic has, of course, changed the situation fundamentally and, at this time, any prediction of the future seems full of uncertainties; but the pandemic also showed the world the challenges related to the already stressed and exhausted global supply chains. In the end, the pandemic may drive a fundamental shift towards new technologies that are technologically advanced and offer significant cost savings. Furthermore, the COVID-19 outbreak shows the advantages and flexibility of AM; hundreds of thousands of products around the globe have been made by polymer, and to a lesser extent metal,

to assist in efforts to fight and contain the pandemic, such as face masks, door openers and others. To design and manufacture these products in such a short space of time would have been far more challenging using conventional manufacturing methods that require tools, fixtures, etc.

Conclusion

Element 22's position as a leading expert in the Metal Injection Moulding of titanium is based on more than twenty years of intensive research and development. This activity still continues, but the company is now able to reap the rewards of its efforts with a diverse range of successful, high-performance applications. This success, however, should not be read as a sign that the sinter-based processing of titanium is anything other than extremely challenging, requiring total control of the complete process, from incoming powder handling to debinding and sintering. With this expertise now also being applied to sinter-based AM processes such as Binder Jetting and Material Extrusion, the AM industry is once again able to benefit from 'fast-track' process development thanks to the MIM industry's expertise. It will be interesting to see how successfully the MIM industry can grasp the opportunities that will inevitably follow.

Contact

Matthias Scharvogel
Element 22 GmbH
Wischhofstrasse 1-3, Geb. 13
D-24148 Kiel
Germany
matthias.scharvogel@element22.de
www.element22.de

Author

Dr Georg Schlieper
Harscheidweg 89
D-45149 Essen
Germany
georg.schlieper@hotmail.de



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Digitising part production: A new approach to creating unique part IDs for MIM components

Terms such as Industry 4.0 and the Digital Twin trace back to the growing trend to digitise industrial processes. Modern production equipment delivers a huge quantity of process data, and the continuous analysis and correlation of these data could result in process stability improvements, less scrap and enhanced traceability. For such advances to be applied to MIM production, the permanent surface marking of each part with a unique ID is required. In this article, Prof Dr-Ing Frank Petzoldt and Lutz Kramer, from Fraunhofer IFAM, Bremen, Germany, report on the development of a process that offers a cost-effective solution to what currently poses a significant technical challenge.

Product labelling is today standard in most industrial production chains. The Metal Injection Moulding industry, using a now-mature technology for the production of large numbers of complex-shaped parts, also offers its customers solutions to mark finished components. Most commonly, serial numbers are printed or laser marked on the surface of MIM parts. Another option is the embossing of codes onto finished parts. This identification of individual parts, allowing a certain level of tracking of their production history, is often required for safety-relevant components in the aerospace or medical sectors.

There is, however, another motivation for marking MIM parts individually: the growing trend to digitise whole production processes. Through digitisation, the continuous improvement of each single MIM process step is possible, increasing the quality level of the produced parts and reducing scrap rates. One major step towards zero-defect production would be the individual

surface marking of MIM parts directly during injection moulding. In this article, a new method of marking, using Additive Manufacturing to produce individualised mould inserts, is introduced. The marking of each individual part

with a unique code in the green state presents the opportunity to add significant value along the entire process chain. The technical feasibility of such a development, as well as economic considerations, are reviewed in this article.



Fig. 1 Data matrices such as this can be found in all aspects of modern life, but their application in processes such as MIM production is only just being explored

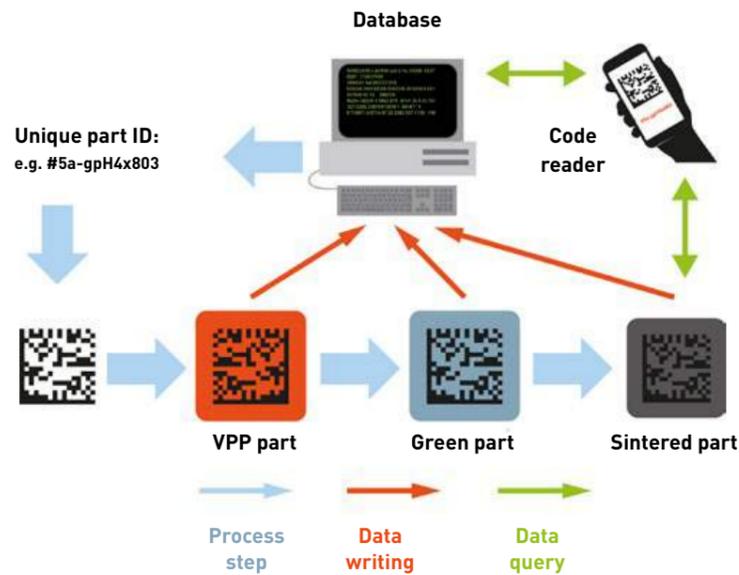


Fig. 2 Labelling process and data acquisition along a Metal Injection Moulding production line

Symbol size	Number of IDs
10 x 10	1 million
12 x 12	100 million
14 x 14	10 quadrillion

Table 1 Storage capacity of a data matrix code in bits after Laserax [2]

A new approach to create part IDs for metal injection moulded components

Laser marking on the surface of a sintered part is the conventional method used to identify individual parts for any kind of aftersales services. This state-of-the-art technology, however, has at least one significant drawback: the marking is produced after the MIM part has been produced. Thus, correlating the unique production process parameters from each step of the production process chain to determine an individual part's quality is impossible. So, is there a solution

that can enable the digitisation of MIM part production along the production chain, from the green to the sintered and finished part? For this, a technically and economically feasible method to mark green parts individually during injection moulding is required. Today, this appears to be possible through a combination of Additive Manufacturing, intelligent data acquisition and MIM technology.

To achieve the ambitious goal of 'close to zero defect' production, a number of steps are necessary:

- Generate a unique individual label using a data matrix code
- Minimise the size of the marker

- Produce these individual data matrix codes as robust plastic mould inserts by an AM process, in this case Vat Photopolymerisation (VPP), also known as Digital Light Processing (DLP) or Stereolithography
- Read the code and place the insert by robot into the mould
- Transfer this code during conventional injection moulding onto the green part's surface. The code must be readable in both the green and sintered state
- Install a computer network that allows continuous and permanent tracing of all relevant parts and process parameters
- Correlate these data to individual part quality measures

As shown in Fig. 2, a database should contain unique part IDs. From these IDs, a data matrix code can be generated. This code serves to link all process and part parameters with the database. In an industrial environment, the code is read via standard barcode readers. The database query will be accepted and processed by a script that runs in the background, and will be concluded by issuing a product data sheet.

The use of data matrix codes for component labelling

The decision must be made as to which type of code is most appropriate for a mass production process such as MIM. The most important criteria are reliability, readability, and data safety. For these reasons, 2D codes and in particular the 'data matrix' are currently the most widely used codes in industry. The robustness of this system means that codes are readable even if up to 39% of their features are destroyed [1].

The storage capacity of a data matrix, measured in bits, is shown in Table 1. Simply by adding a single module row, an exponential increase in storage capacity and the number of individual IDs can be achieved, with only a marginal increase in the required surface for the ID.

A 10 x 10 data matrix is suitable to mark one million MIM parts individually with a minimal area of the part's surface being required. The inserts are, of course, only used once. To generate information about the readability of different geometries such as squares or circles, and their dependency on coverage and code width, a series of experiments was planned. A direct and permanent part ID must survive the whole MIM process cycle and readability of the code must be assured in all production stages (insert, green part, brown part, sintered part, finished component). The most critical steps are debinding and sintering of the MIM parts, where there is the highest risk of losing features of the ID code due to, for example, chemical attack and shrinkage.

To find a suitable geometry for the highest quality forming and readability of the code, experiments with different layouts were performed, as shown in Figs. 3 and 4. All codes were created from squares and circles. The code width varied between 3–6 mm and the relative coverage was changed to between 50–90%.

Additive Manufacturing with Vat Photopolymerisation

Vat Photopolymerisation (VPP), also known as Digital Light Processing (DLP), is a very promising Additive Manufacturing technology for the production of huge quantities of individual resin mould inserts reliably and cheaply with the required resolution. The inserts are created in a container filled with a liquid monomer, which

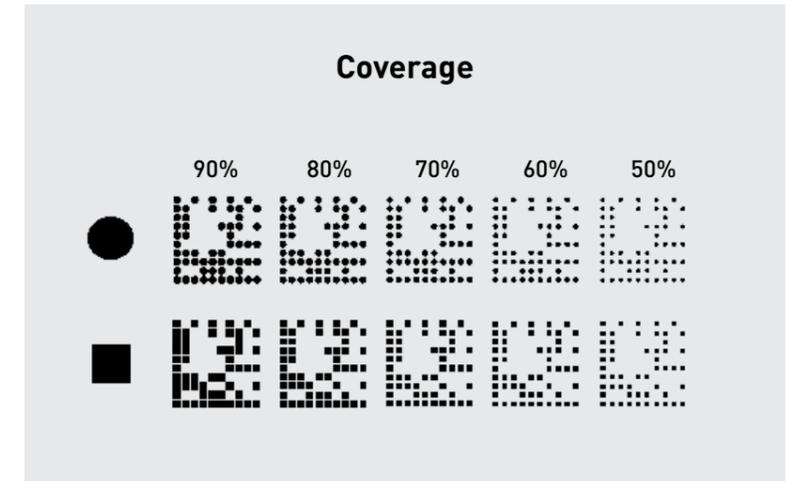


Fig. 3 Relative coverage for the data matrix codes

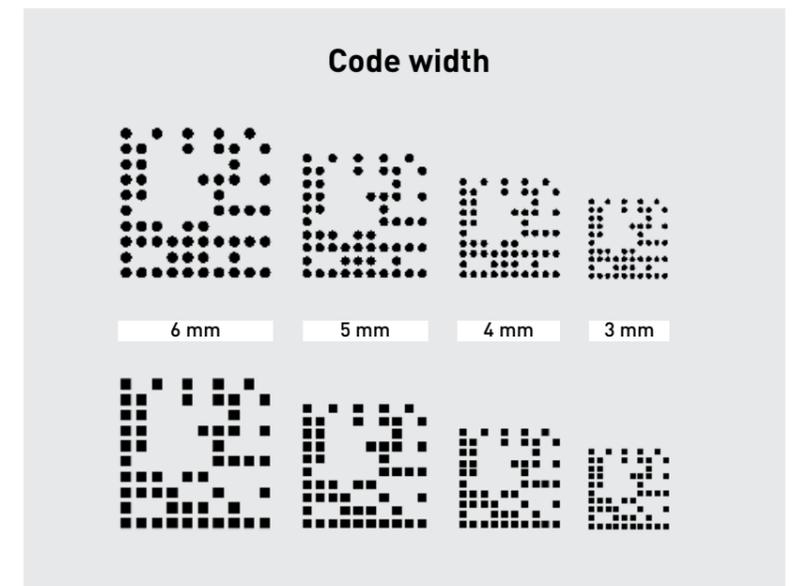


Fig. 4 Code widths for squares and circles

is an acrylic resin that reacts to a certain frequency of light. An adjustable build platform is initially placed in its highest position, submerged in a thin layer of liquid monomer.

A projector, combined with an angled mirror, projects a series of images across the entire platform to polymerise the complete cross-section. The platform is lowered so that the previous layer is now covered by a new, thin

layer of liquid. The projector then solidifies a new layer which sticks to the previous layer. The process is repeated until the insert is completed and is finally cured in an UV oven. This process is suitable for the mass production of small mould inserts with individualised data matrix codes; a UV-hardened acrylic resin is used as it can withstand the typical moulding temperatures found in Metal Injection Moulding.

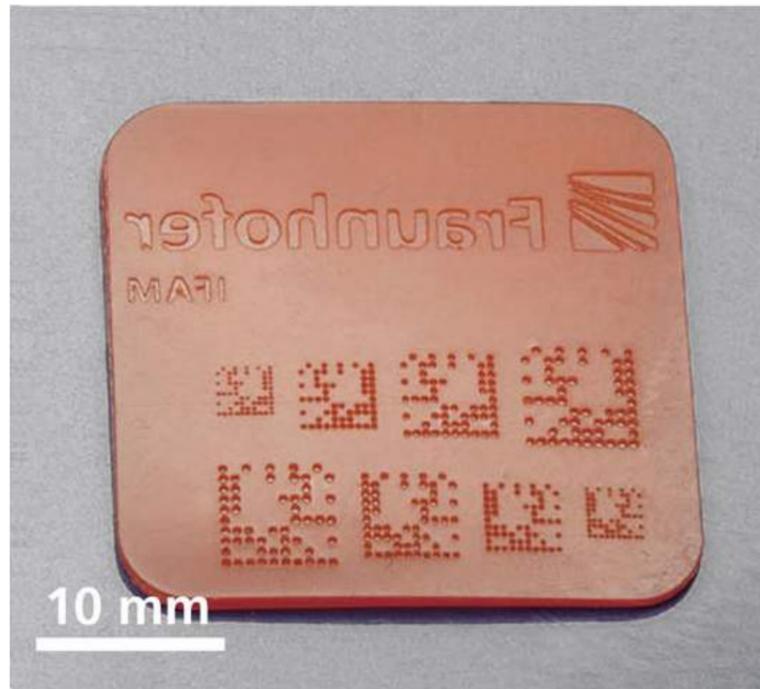


Fig. 5 Data matrix codes produced by VPP

Fig. 5 shows an example of a VPP-produced part with data matrix codes as depicted in Fig. 4. These test structures were used to analyse readability using a standard code reader with a smartphone app. It is particularly important to correctly illuminate the insert to guarantee readability when using a standard camera. In addition, the readability of the insert's 'mirror image' structure is a prerequisite, as the insert is a negative of the structure that appears on the finished MIM part. The inserts can be used randomly in MIM part production, during which they can be picked by a robot from a container and scanned before being inserted into the mould.

Digitised MIM process

To perform readability tests, 30 x 30 x 4 mm square blocks were produced by VPP, with each insert having eight different codes (see Fig. 4). These blocks were inserted manually into a suitable mould. Green parts were made from a 316L feedstock on a Boy-XS injection moulding machine. After each cycle, a new VPP insert was used. All parts were then sintered in an Elnik Systems MIM 3001 furnace, using standard sintering conditions for 316L.

In Fig. 6, a detailed view of the data matrix code of the VPP insert is compared with those in the green and sintered state. The pins are circles with a coverage of 80%. It can be reported that there is complete readability in all stages of the MIM production process, demonstrating the general suitability of this kind of labelling for MIM part production. A significant advantage of reading the code after injection moulding and after sintering is the opportunity to correlate process parameters with individual quality criteria of the part. Following the concept shown in Fig. 2, an intelligent data acquisition system could be combined in the future with artificial intelligence to find strong correlations and thereby reduce scrap rate.

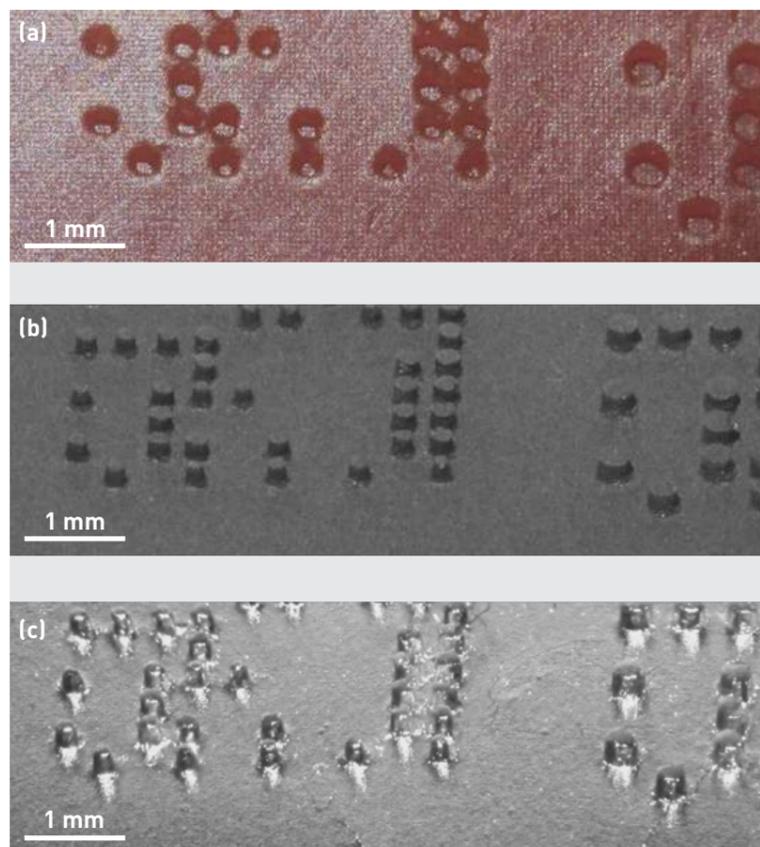


Fig. 6 Data matrix code: (a) DLP insert (b) green part (c) sintered part

Coverage [%]		90				80				70				60				50			
Code width [mm]		6	5	4	3	6	5	4	3	6	5	4	3	6	5	4	3	6	5	4	3
●	VPP	100	100	100	100	100	100	100	100	100	100	100	100	50	0	0	0	0	0	0	0
	MIM	100	100	100	100	100	100	100	33	100	100	100	100	67	83	67	67	17	33	50	83
	Sinter	83	100	100	100	100	100	100	100	83	100	100	100	17	17	0	17	17	17	17	0
■	VPP	50	100	100	50	100	100	100	100	100	100	100	100	50	100	50	50	50	0	0	0
	MIM	50	50	50	0	100	100	100	100	100	100	100	100	83	100	100	100	33	17	50	83
	Sinter	67	67	67	50	100	100	100	83	83	100	100	100	67	83	100	67	0	0	0	0

100% readability 0% readability

Table 2 Readability of data matrix codes

Dot parameters in µm				Dot shape	Readability
Edge length	Distance	Height	Coverage		
364	47	452	90%		63%
314	91	507	80%		96%
273	138	346	70%		96%
227	183	247	60%		79%
180	321	6	50%		0%

Table 3 Dot shape for squares and readability after sintering for different coverages

A more detailed analysis of the readability from each step is shown in Table 2. Since there was no discernible difference due to the mirroring of the codes, codes of the same size and width are combined to make forty different ones. It was shown that codes with a reduction in the coverage, and thus a pin footprint below 70%, led to a sharp drop in readability. This was true for both round as well as square shapes. In contrast to the use of round shapes at 90% coverage, the use of square shapes with a coverage of 90%

showed much poorer readability. The best readability in the sintered component was achieved by reducing coverage to 70%. In Table 3, the influence of coverage on the structure of the pins after sintering is shown for squares. The given dot parameters are for the fifth pin from right hand side. It can clearly be seen that a too-high coverage of 90% results in a type of closed or solid wall after sintering, drastically decreasing readability. The shrinkage after sintering is 18.3%. It is also obvious

that a decreasing dot height reduces the readability of the code. From these experiments, optimum dot parameters and coverage were defined. The feasibility of the above described method was shown with a demonstrator which includes the smallest data matrix code (10 x 10 module) at 80% coverage, resulting in a 2.4 mm code length in the sintered state and excellent readability. The content of the code (a random ID number: 781399) can be read via a smartphone using

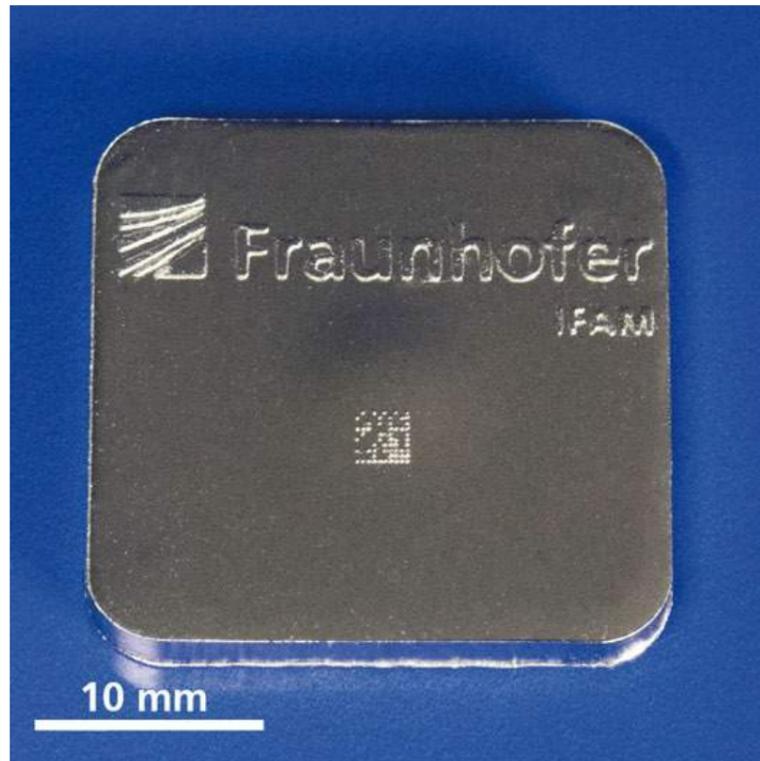


Fig. 7 Demonstrator with a data matrix code [3 mm code width in the green state]

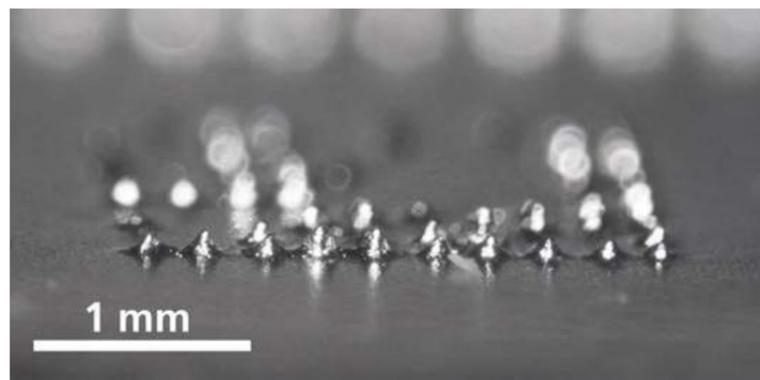
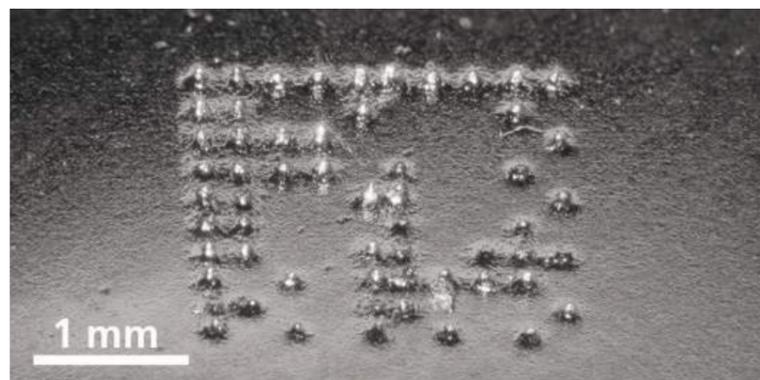


Fig. 8 Detail of the demonstrator component's data matrix code

an appropriate app without any additional tools, so long as the illumination is sufficient (Figs. 7 and 8). With this demonstrator the feasibility of using VPP mould inserts as lost markers was proven.

Economic considerations

With regards to cost calculations, there are a number of aspects to be considered. These include the production cost of the VPP codes, the handling time required to place the insert into the mould, and the overall lengthening of production cycle time. The estimated production cost for one VPP insert is between €0.01–0.02. Handling will extend the cycle time by approximately two seconds, resulting in a reduced total production capacity. Summing up the additional cost per part, they are in the range of a few cents per part. In comparison with the cost for laser marking of the finished sintered part, such an approach can be regarded as competitive.

Additionally, there are numerous potential advantages including scrap rate reduction, traceability of individual parts from MIM mass production and the opportunity to analyse production data using artificial intelligence tools. All these benefits should be calculated to the cost benefit of such an approach for digitising MIM production.

Industry 4.0 is a key factor for further success

Marking the components individually offers the advantage that all data is stored centrally in a database and no data storage in or on a component is required. In addition, the implementation of a database offers the advantage that the component only has one interface – the optically readable code – as an access point to all

relevant data. Such an approach also offers a security advantage as the component itself does not contain any sensitive data.

However, it must be ensured that the database is sufficiently protected, since the records for all produced components are stored together. At

To be successful on the path towards zero-defect production, it is a prerequisite that each part must be identified by an individualised marker. If this requirement is fulfilled, a machine data acquisition system can be used to follow the production history of each individual

history. As such, it is an important step in the direction towards zero-defect production in MIM.

Authors

Frank Petzoldt and Lutz Kramer
Fraunhofer IFAM
Bremen
Germany
frank.petzoldt@ifam.fraunhofer.de
www.ifam.fraunhofer.de

The practical work and proof of the described concept were performed by Niklas Lehmann, Torben Reck and David Weber within their Master Project at University Bremen, Germany

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“Modern production equipment delivers a huge quantity of process data, and the continuous analysis and correlation of these data will result in an improvement of process stability and, eventually, in less scrap.”

the same time, access to the data belonging to a component must be kept sufficiently simple so that, for example, components for maintenance cases can be accessed easily and quickly. However, this poses a potential security risk because, depending on the data access device and the method of transferring the data, unauthorised access can take place at precisely these points if no further security measures are installed.

Today, cyber-physical systems are becoming ever more important. Such systems are connecting production machines, produced parts and production logistics with their digital twins. Modern production equipment delivers a huge quantity of process data, and the continuous analysis and correlation of these data will result in an improvement of process stability and, eventually, in less scrap. For a mass production process such as MIM in particular, this is a great opportunity to improve process stability. Using statistical analysis of sensor data along the process chain and finding an appropriate correlation between quality criteria of parts and process parameters then becomes an opportunity for further development through the use of artificial intelligence tools.

MIM part. In the future, this information will be directly connected to process simulation tools, including mould flow simulation and sintering simulation.

Conclusions

The topographic marking of MIM parts in the green state by means of additively manufactured mould inserts is a new process. Each produced part has an individual data matrix code which can be connected to all production parameters along the process chain. The results show that a 'fingerprint' for each part has many advantages, and presents the opportunity to benefit from a huge variety of correlated data. All quality-relevant data are available in a central database, and can be accessed simply by reading an optical code on the part.

The data matrix codes can be generated automatically using separate software. There is every chance that this process will become a first evolutionary step from a pure ID-system to a true information system. This will in the future enable the linking of all information from a relevant database to an individual part and its complete production

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Making the business case: How sinter-based Additive Manufacturing can compete with Powder Injection Moulding

When it comes to closely related manufacturing processes such as Powder Injection Moulding (PIM) and sinter-based Additive Manufacturing, the ability to design a part that could be produced by either process has numerous advantages. Loran Mak, from AM machine developer Admatec Europe, and Harrie Sneijers, from sister company and PIM specialist Formatec Technical Ceramics B.V., present an overview of Vat Photopolymerisation (VPP) and PIM technologies and, through two case studies, highlight how the advantages of the processes can be leveraged when making the business case for each application.

Small, complex metal and ceramic parts are in high demand in numerous international markets. Manufacturing processes such as Powder Injection Moulding (PIM), a term that encompasses Metal Injection Moulding (MIM) and Ceramic Injection Moulding (CIM), have been able to serve these markets well and continue to flourish. However, in the current rapidly evolving commercial environment, many of the small components that are being designed have ever more complex geometries, seek to make use of more ambitious design freedoms, and come with a demand for much shorter lead times. Geometries that challenge PIM's current shaping capabilities are, therefore, creating new opportunities for the Additive Manufacturing industry, most notably for sinter-based Additive Manufacturing processes. So, what are the opportunities for these processes to complement PIM, and how do the numbers stack up?

The evolving drivers for technical ceramics and metal parts

Currently, some of the most prevalent markets for PIM components are for applications in the medical sector, including surgical instruments and

implants, as well as laboratory equipment, 3C applications including fibre optic connectors (Fig. 1) and 5G antennae, and industrial sensor components. Other markets include aerospace, energy, electronics, luxury goods and jewellery, automotive and the chemical processing industries.

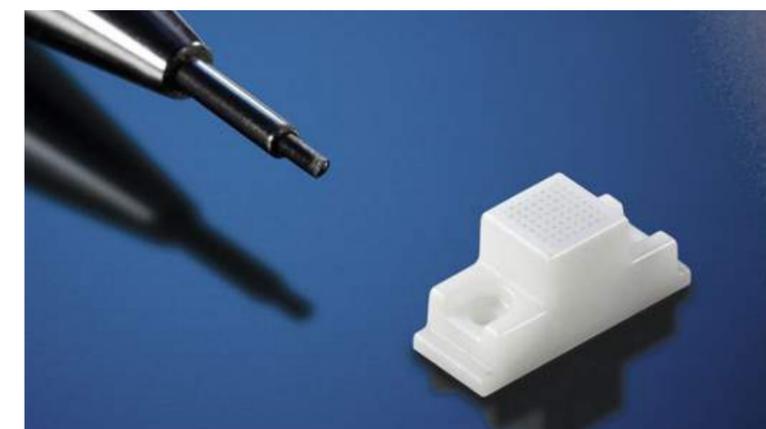


Fig. 1 A small CIM part. This fibre optic ferrule features sixty-four octagonal shaped holes, each of 125 µm diameter, positioned on a surface of 2 x 2 mm. The part requires no post-sintering finishing operations [Courtesy Formatec]



Fig. 2 A stainless steel nozzle manufactured by AM and an inset SEM showing the microstructure of a sintered 316L AM part, both produced on the Admaflex 130 [Courtesy Admatec Europe]

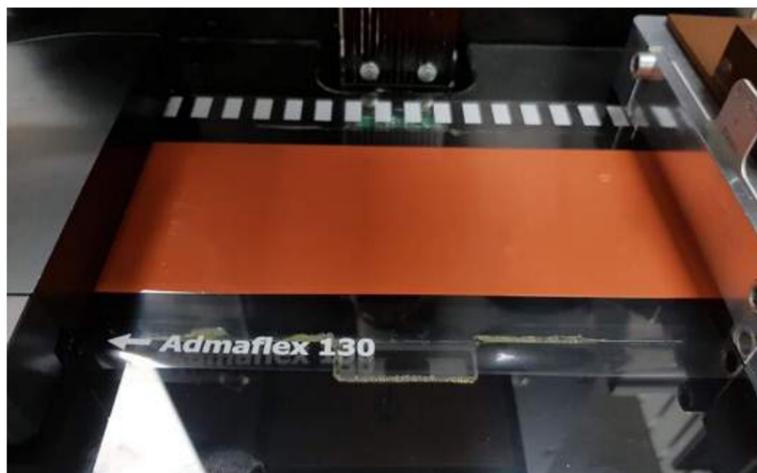


Fig. 3 Interior view of an Admaflex 130 containing a copper-filled resin for the production of the parts shown in Figs. 4 and 5 [Courtesy Admatec Europe]

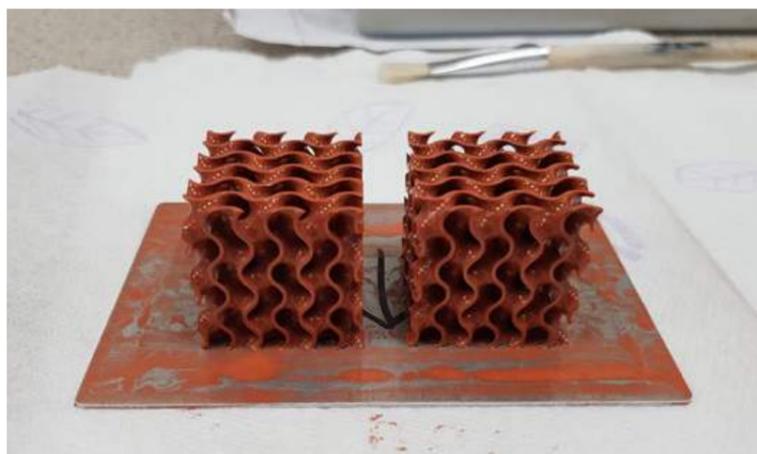


Fig. 4 Cured copper parts as removed from the build chamber and prior to thermal processing [Courtesy Admatec Europe]

Whilst PIM remains a crucial technology for these markets, there is a noticeable shift towards Additive Manufacturing as a complementary production process. Such a shift can be attributed to an increasing desire for more flexibility during a component's development cycle, as well as a demand to perform tests using fully functional prototypes. Additionally, the ability to modify designs at any time during the development stage is a major attraction.

AM also presents greater opportunities for new applications or products where there is an increased integration of functionality, and where, in the case of ceramics, such a class of material might not even have been considered as an option. Finally, AM is enabling the production of high-performance metal and ceramic components to expand from the mid- and high-volume markets served well by PIM to new, low-volume applications, for example from just five to fifty parts per year, whilst incorporating advanced features such as complex internal channels.

Materials suitable for use in PIM and sinter-based AM

Most sinterable metal or ceramic materials are suitable for application in both PIM and AM processes, enabling a wide span of applicability for many industries. The main consideration is that the material should be sinter-active, meaning that the correct powder composition can be processed to the required particle size range. Sinterable metals and oxide ceramics are sinter active, whereas non-oxide ceramics need an additional force or sinter aid. To attain a dense product after sintering, the primary powder size should be sufficiently small, typically 1 µm for ceramics, but for more sinter-active metals even 30 µm particles can result in sintered densities of 98–99% (Fig. 2).

In addition to popular PIM materials such as 316L and 17-4 PH stainless steels and Inconel, increasing

demand has been seen for materials with high thermal and electrical conductivities. Copper has recently gained increasing interest because of its anti-microbial properties, which have become a hot topic as a result of the coronavirus (COVID-19) pandemic (Figs. 3-5).

Powder Injection Moulding and Admaflex DLP; the differences explained

PIM and sinter-based AM processes use related production steps to shape 'green' parts, which then undergo similar thermal debinding and sintering cycles. Both processes can deliver fully dense parts (> 99% density) in ceramic or metal when using appropriate powder sizes and sintering parameters, and both can utilise the same debinding and sintering equipment.

Powder Injection Moulding

PIM is an established production method for shaping relatively complex components from ceramics and metals, and is especially interesting once substantial production volumes are required. During the injection moulding process, a highly-filled thermoplastic feedstock is shaped within a mould. The fixed mould wall allows high reproducibility and narrow tolerances in the green part. After a design freeze, a typical period of eight-to-twelve weeks is required for mould manufacture and the production of zero series for part release. Once qualified, the PIM process benefits from the ability to be readily upscaled to higher production quantities.

Typical annual production volumes range from a thousand to one million pieces. With PIM, the mould cavity can be produced to an extremely high accuracy and, by applying controlled production parameters such as cavity pressure and temperature, high repeatability and narrow tolerances can be achieved in the green part. Parts with holes of 125 µm with tolerances of only 2 µm have proven to be possible with high-precision tooling



Fig. 5 A sintered copper part, produced on the Admaflex 130, after sintering [Courtesy Admatec Europe]

and reproducible debinding and sintering without any post-machining steps (see Fig. 1).

Admaflex DLP technology

AM is a means of producing parts, layer by layer, from a digital file (STEP/STL). Also known as 3D printing, the technology was first

introduced in the mid-1980s for model making and prototyping (in plastic), but over time has evolved into a set of valuable production technologies. Today, AM is used for the fabrication of functional end-use products in a diverse range of materials, from plastics, metals and ceramics to biomaterials. Within the ISO Additive Manufacturing process categories, Admatec's Admaflex Digital Light Processing (DLP) technology falls into the Vat Photopolymerisation

“With PIM, the mould cavity can be produced to an extremely high accuracy and, by applying controlled production parameters such as cavity pressure and temperature, high repeatability and narrow tolerances can be achieved in the green part.”

introduced in the mid-1980s for model making and prototyping (in plastic), but over time has evolved into a set of valuable production technologies. Today, AM is used

(VPP) category, also known as Stereolithography. The process uses a highly-filled UV sensitive resin, which is exposed, layer by layer, using UV curing.

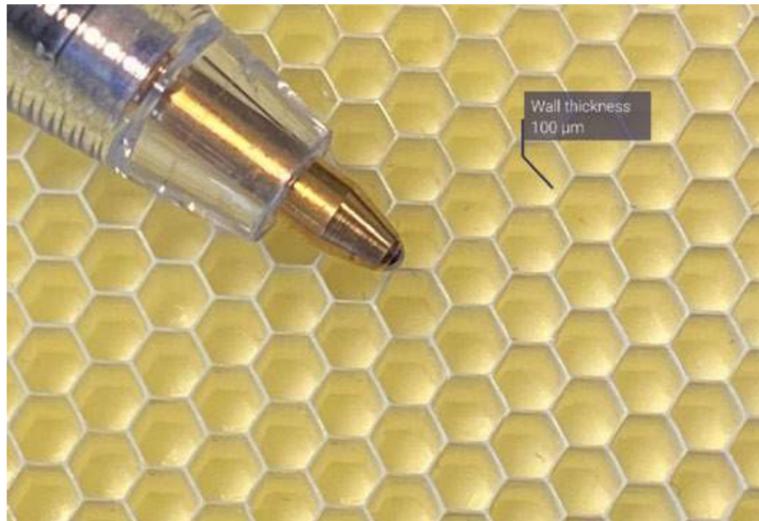


Fig. 6 An example of a thin-walled ceramic AM part. This honeycomb structure is used in electronic applications such as 5G antennae and medical systems. The wall thickness is in the range of 100 µm [Courtesy Admatec Europe]



Fig. 7 A component for a surgical instrument that functions as a wire guide [Courtesy Admatec Europe]

Initially, AM-processed components exhibited a 'staircasing effect' due to roughly stacked layers that many may remember from the first rapid prototyping machines, but this effect has been reduced to smooth surfaces by post-machining or by building Z

layers in reduced steps in the 20 µm range. With resolution from Admatec's DLP systems in the X-Y plane reaching 15–50 µm, and building speeds and volumes ever increasing, the opportunities for manufacturing highly accurate end products is growing.

In green parts made via DLP, the layers in the Z-direction can still be visible under a microscope. Typically, after sintering, this effect can no longer be observed because of the controlled shrinkage of the component, and for most materials, surface roughness is below 1 µm (Ra).

Using DLP for the Additive Manufacturing of metal and ceramic parts has an additional useful advantage: the layers are cured in one total projection per layer. The DLP process cures a complete layer in a matter of seconds, allowing up to 300 layers to be built per hour. The build speed is independent of the number of products placed in the build area. If a hundred parts fit, they are processed as fast as a single part.

Unlike with PIM, AM has no fixed mould wall, and the ability to control the free forming process determines achievable dimensional accuracy and component resolution. This is dependent on several factors such as the pixel size of the DLP light engine, the layer height and the scattering of the light inside the cured layer, resulting in over-cure or under-cure. Modern DLP systems use light engines with a resolution of 2,560 x 1,600 pixels, which means that square pixels of 15–88 µm can be switched on or off to determine the wall thickness of a green part. Typically, the accuracy of injection moulding is higher than this type of process; however, with a pixel size of 35 µm, it is possible to manufacture honeycomb-like parts with wall thickness in the range of 100 µm [Fig. 6].

Whereas the size of a part in the PIM process is determined by the dimensions of the mould and the flow of the thermoplastic feedstock, the maximum size for fully dense parts made via DLP depends on the build platform of the machine. Both manufacturing processes have design guidelines and directions to optimise production, capacity and the total time needed.

Environmental considerations

In terms of waste, whilst both processes can claim distinct 'green' credentials, AM can be a more

advantageous choice as waste is virtually zero, due to uncured feedstock material being easily reused. PIM, on the other hand, produces runners and sprues that, whilst able to be reground and reused, are not infinitely recyclable, as the polymers used in the feedstock deteriorate with each thermal cycle. With ceramic feedstocks in particular, recyclability is limited by the risk of metallic contamination, which can lead to defects or porosity.

Case study examples comparing PIM and AM

Surgical instrument component

For this application, shown in Fig. 7, several product variations were evaluated. This particular product covers part of a surgical instrument designed to guide a wire. Traditionally, iterations of such designs were performed using resin models. These provide answers for geometric fitting tests only; the resin simply does not deliver the full functional requirements of the ceramic or metal product. With additively manufactured parts, three evaluation steps could be taken before a final design was frozen for functional testing. A further twenty-five parts were manufactured for this purpose. After final approval, the design was still open to move to production by either PIM or AM.

Annual production quantities were initially forecast at 10,000 units, with an anticipated rise to 25,000 units per year in the following year. Product life cycle was set at five years; however, this was based on current models of mould life expectations, rather than innovation opportunities or marketing strategies.

Comparing PIM and AM in this application, PIM would require a four-cavity mould with one slider, commercially quoted at €18,000 for the required tolerances and with a shot guarantee of 150,000 parts. Price per part would be €0.45 at a minimum ordering quantity of 5,000 parts, while production capacity,

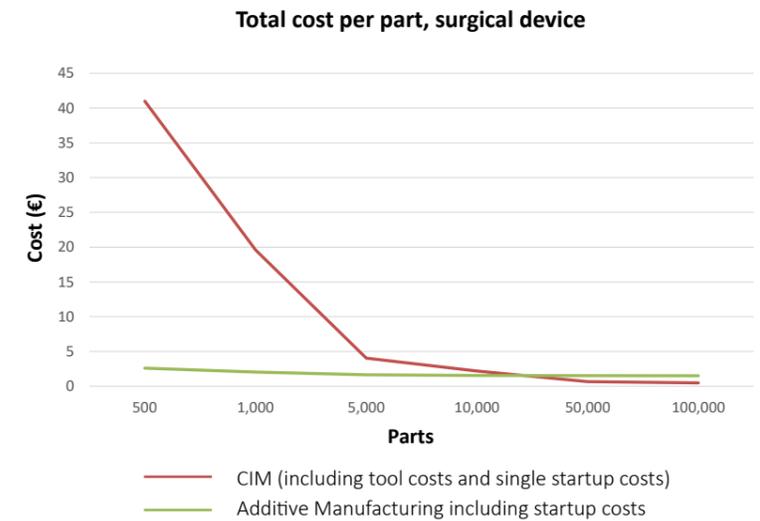


Fig. 8 The relationship of costs versus total number of surgical device parts ordered. This puts the breakeven point for Additive Manufacturing versus Injection Moulding in this case at about 20,000 parts

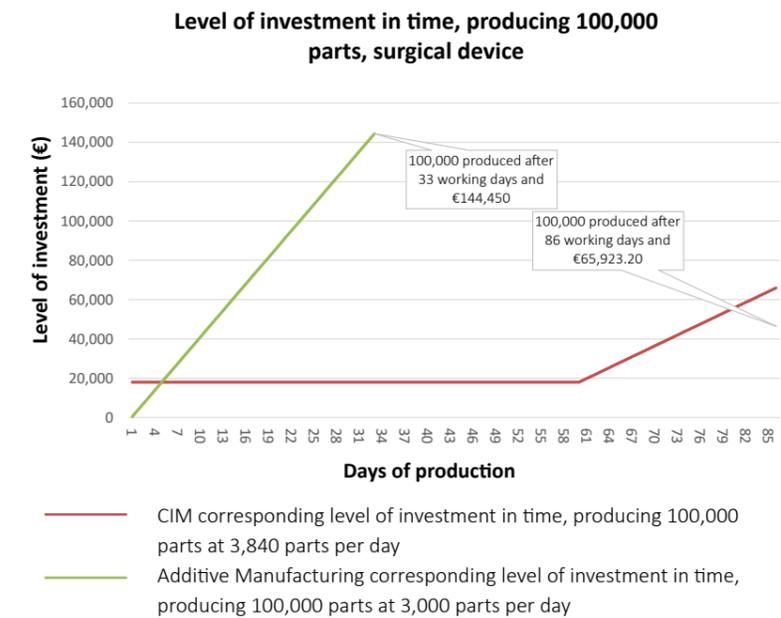


Fig. 9 Shows the level of investment over time for the surgical device case study while producing a fixed total volume

based on the injection process cycle time and the use of four cavities, would be 3,840 parts per day. This was for production without the automation that would enable unmanned night production. Typical manufacturing time for the tool was estimated at eight to twelve weeks. Figs. 8 and 9 illustrate the relation-

ship of costs versus total number of surgical device parts ordered and the level of investment over time. Whilst Additive Manufacturing is a more expensive process, there is no differentiation between prototype parts, start-up series, first series and intermediate design changes. The first samples were produced and



Fig. 10 Surgical device parts produced during evaluation steps and the first additively manufactured parts for functional testing (Courtesy Formatec)

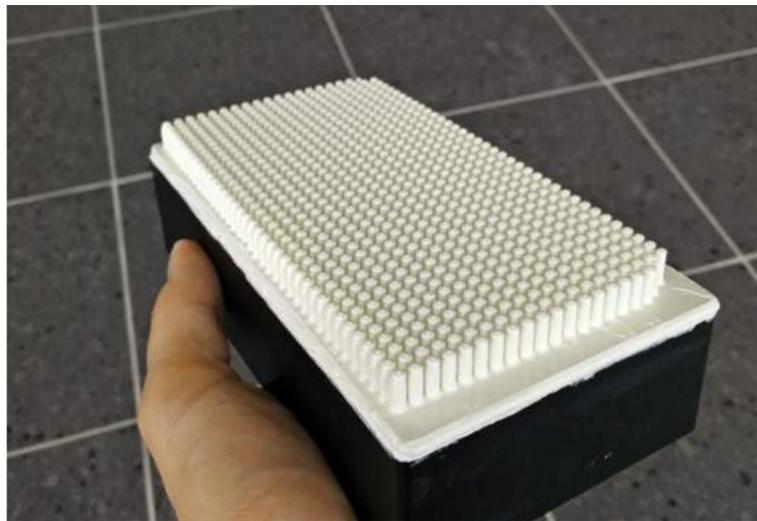


Fig. 11 Every two hours a batch of 750 parts was produced by Additive Manufacturing (Courtesy Formatec)



Fig. 12 The ceramic sensor housing (Courtesy Formatec)

sintered in the evaluation steps as described above. The costs for these first low-volume runs were considerable, with single start-up costs at €450 and a €34 per part cost. However, these costs were justified because they eliminated the far more costly setbacks at subsequent Technology Readiness Levels in the product development cycle.

A first zero series was produced within three weeks after the design freeze, including sintering. This saved on both cost and time for mould production. Further batches were manufactured, producing 750 parts per two-hour run (including machine setup times). This set the production rate at $4 \times 750 = 3,000$ parts per day. For these batch sizes (with an ordering quantity of 500 parts), production cost was €2.10 per piece.

At this stage, the main consideration is whether a low-cost, flexible and fast start-up and initial two years of production is more important, or whether confidence in future sales is high enough to invest in a lower price per part over the product's total lifetime.

For Additive Manufacturing, it should be noted that benefits of scale are achieved by the ability to produce multiple parts in one run. In this case, the part's geometry was beneficial to Additive Manufacturing since many parts could be fitted into one production run (Fig. 11). For parts where the Z-height increases, build time and therefore costs increase rapidly. Additionally, if size increases in the X-Y dimensions mean that fewer parts can be produced per run, the balance again shifts rapidly.

When the point is reached that a customer is happy to invest in tooling after a trial period with the AM parts, PIM can reduce part prices substantially, with larger quantities delivered in a shorter time. The elements that contribute to this price drop are: less handling of green parts, lower machine costs, and the price difference between the PIM feedstock and the materials used in AM. Ultimately, the cost for

tooling is almost of no significance in the part price when a mould could produce up to 500,000 shots. It is important that customers communicate with reliable PIM companies, who can advise them on which strategy will best suits their needs and make their project a success.

Sensor housing

A second case study is for a sensor housing (Fig. 12). This part has a Z-height of 28 mm, and would need support structures to be manufacturable by DLP, involving a costly manual reworking cost per part. Because of the part's X-Y dimensions, only fifteen can be manufactured in one AM run. When compared with Powder Injection Moulding, it can be seen in Fig. 13 that the break-even point for total cost per part is already achieved at 600 parts. This production volume would be reached after twenty working days for Additive Manufacturing and sixty-one working days for Powder Injection Moulding – primarily as a result of the time required for tool making.

A shorter time to market and lower level of early investment might justify the higher cost per part for Additive Manufacturing. It will take Additive Manufacturing over 300 days to produce the full batch (Fig. 14). This speed could be divided, however, by the availability of machines for parallel production, whereas in Powder Injection Moulding this is impossible as there is only one tool available. For quantities over 600 parts, however, CIM rapidly becomes more attractive in terms of total cost per product (tooling costs included) and production time.

PIM and AM in times of crisis

We are currently experiencing a crisis on a global level due to the coronavirus (COVID-19) pandemic. A sudden demand for medical parts has arisen and, as a response, many AM machines have been used worldwide to produce parts for personal protection, ventilators and

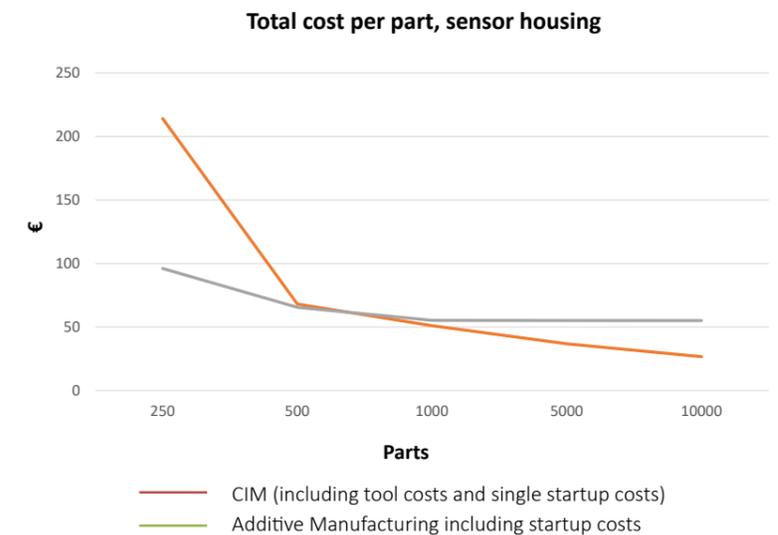


Fig. 13 The relationship of costs versus number of parts totally ordered for the sensor housing

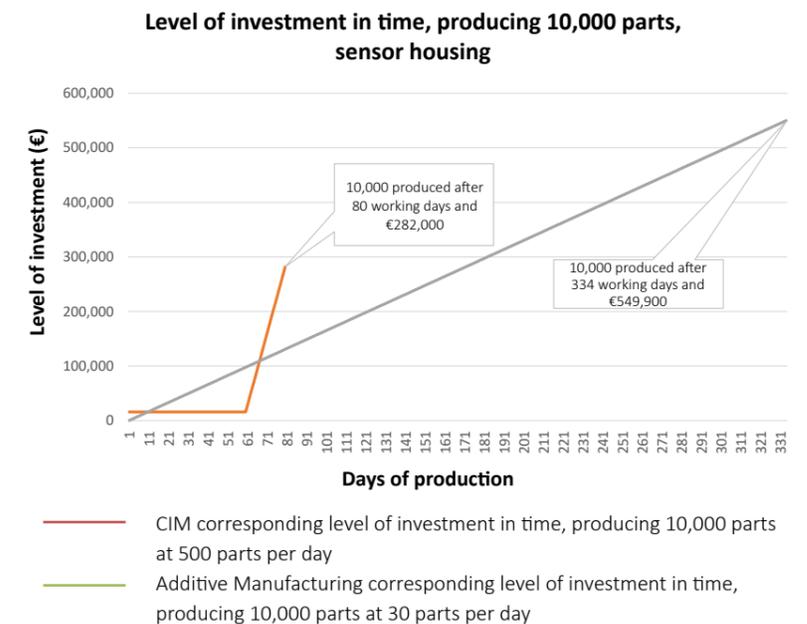


Fig. 14 The level of investment over time while producing a fixed total volume

other medical devices. For example, a government laboratory, which already used ceramic AM for safety and energy applications, switched to the production of ceramic parts for medical applications within a few days. As demonstrated in these two case studies, initial costs and time-

to-market are quite different with PIM and AM. In normal business situations there is time to consider all relevant production processes, as well as a window of opportunity to design and produce a mould. In a crisis where there is a sudden urgent demand for a particular

	3D printing	3D printing / machining	Moulding	Moulding / machining / grinding
Lead time in weeks	4 wks	6 wks	8-10 wks	10-12 wks
Production quantity	1-1,000	1-1,000	100-10,000+	100-10,000+
Investment	•	•	•••	•••
Price level parts	•••	•••	•	•
Complexity	•••••	•••••	••••	••••
Flexibility to redesign	•••••	•••••	•	••
Size max. (box)	96 x 54 x 120 mm	96 x 54 x 120 mm	60 x 60 x 60 mm	60 x 60 x 60 mm
Tolerances	± 0.5%	± 0.3%	± 0.3%	± 0.01 mm
Surface *	0.8-1.6 Ra	0.3-1.6 Ra	0.3-0.4 Ra	0.3-0.4 Ra

* The surface quality of all processes can be improved by a polishing process.

Fig. 15 A comparison of the main benefits and limitations of CIM versus VPP technologies

part, PIM can only deliver parts within three weeks if a mould already exists, while AM is 'ready to go' once a design is available. This flexibility in production has proven to be truly valuable.

Conclusion

Both Powder Injection Moulding and Additive Manufacturing can serve a diversity of markets with the production of metal and ceramic components of high geometric complexity. As long as the metal or ceramic powder has the appropriate composition and particle size, there are few reasons why it can't be processed using either technology.

Whereas PIM is a longer-established and more mature production technology, AM is rapidly evolving and establishing its place in the production chain. AM will inevitably mature over time, but is already proving itself in series production, particularly in quantities up to 1,000. Here, it is often superior to PIM, solely because of its time- and cost-effectiveness. Whilst PIM technology offers a lower cost per part once the order quantity is

high enough, delivery times rely on the availability or development of a tool.

Situations can occur where the flexibility and fast response to market of AM is crucial to offer a solution in due time. The far bigger impact, however, will be found in its greater design freedom and production flexibility. New integrated products can be made, providing advanced functionality and decreasing technical limitations. These parts can only be made with AM and will, in certain applications, justify the higher production costs.

The question consistently asked is: Will AM eventually take over from PIM? Based upon the knowledge and experience of Formatec and Admatec, which specialise in both technologies, the belief is that they truly are complementary to each other. Green parts shaped using both PIM and AM can be post-processed in the same furnaces, which is beneficial for PIM companies looking to extend their reach through the Additive Manufacturing of ceramics and metals at a relatively low investment cost compared with, for example, Laser

Beam Powder Bed Fusion (LB-PBF). Additive Manufacturing offers a solution that provides even more design freedom and flexibility and the shortest possible delivery times. This has already proven essential in order to continue supporting customers in emergency situations, such as the current COVID-19 pandemic.

Contact

Admatec Europe
Loran Mak
+31 85 777 101
info@admateceurope.com
www.admateceurope.com

Formatec
Harrie Sneijers
+31 13 530 80 80
info@formatec.nl
www.formatec.nl

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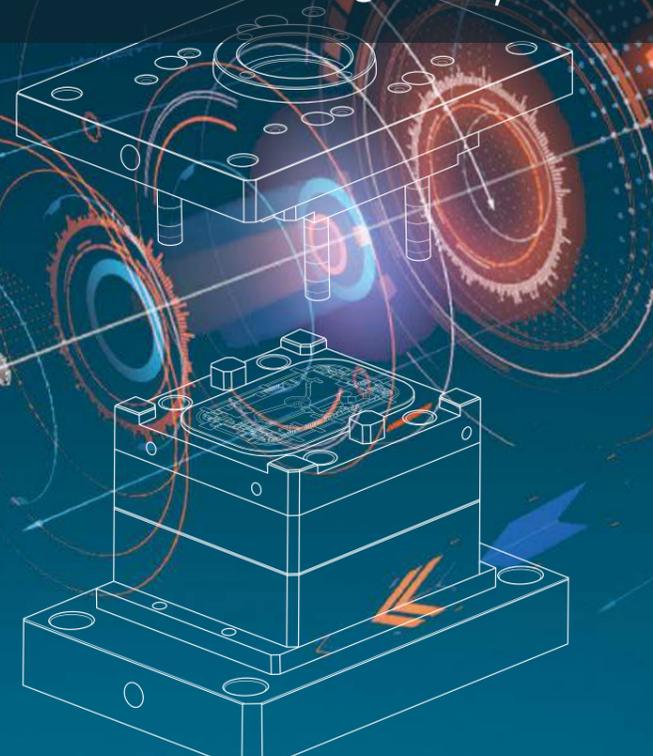
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Reducing MIM part costs with more expensive materials? The re-evaluation of a major 3C application

Metal Injection Moulding is today widely used for the manufacture of 3C components, with 17-4PH and 316L stainless steels dominating production. Other material choices exist, however, that may be better suited to a new generation of 3C applications. In this study by Shin Lee, Chung-Huei Chueh and I-Shiuan Chen, Chenming Electronic Technology Corp. (UNECC), evaluate Co-Cr-Mo alloy (F75) and X15 CrMnMoN 17-11-3 (known as P.A.N.A.C.E.A. by Catamold® users) as an alternative to 17-4PH. Mechanical strength, magnetic properties, corrosion resistance, wear resistance and total cost, based on a major 3C application, are compared. Whilst the conclusions of this study may not be fully applicable to all MIM applications, they provide appropriate directions for MIM end-users and manufacturers to pursue.

Recent technology trends and requests from the 3C industry suggest that MIM component requirements are becoming more demanding, particularly with regard to strength, magnetic properties, corrosion resistance, wear resistance and surface quality. One of the most significant emerging development trends in the 3C industry relates to electromagnetic systems based on advanced metallic materials, combining reasonably high corrosion resistance with excellent mechanical strength, wear resistance and specific magnetic properties (ferromagnetism or paramagnetism, depending on product design and function), using stainless steels and cobalt alloys. 17-4PH is more common than any other type of precipitation hardened stainless steel and has been utilised for a variety of 3C applications including the MIM frame of USB Type C connectors as shown in Fig. 1, as well as the medical, aviation and other industries.

The development of high nitrogen and Ni-free Fe-Cr-Mn-Mo-N austenitic stainless steels is based on a superior combination of properties such as improved mechanical properties, non-magnetism and enhanced chemical properties at the surface for applications in 3C components and biomaterials [1,2]. A new grade of this MIM austenitic

stainless steel, X15 CrMnMoN 17-11-3 (BASF's P.A.N.A.C.E.A.), could be obtained from its original pre-alloyed ferritic steel powder state via solid state nitriding either simultaneously during sintering (a one-step process) or during a solution nitriding after sintering (a two-step process). Atomic nitrogen is absorbed on the surface of the

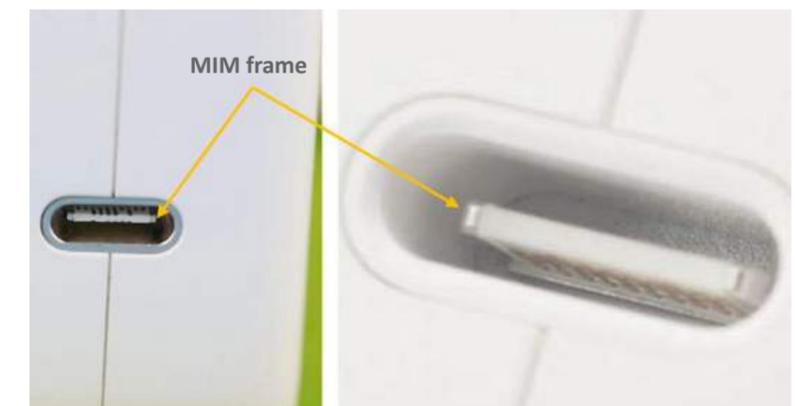


Fig. 1 The metallic frame of MIM USB Type C connector in the power adapter

Material	17-4PH	P.A.N.A.C.E.A.	F75
Advantages	<ul style="list-style-type: none"> • High strength • Low price • Widely-used and easy to obtain 	<ul style="list-style-type: none"> • Nickel-free • Non-magnetic • Good mechanical properties and corrosion resistance 	<ul style="list-style-type: none"> • Biomedical grade • Non-magnetic • Good wear and corrosion resistance
Yield Strength $R_{p0.2}$ (MPa)	≥ 648	≥ 670	≥ 450
Tensile Strength R_m (MPa)	≥ 792	≥ 960	≥ 655
Hardness (HV)	≥ 280	270-300	266-345
Relative Magnetic Permeability (μ_{rel})	95	< 1.01	< 1.01

Table 1 The advantages and material properties of 17-4PH, P.A.N.A.C.E.A. and F75

steel and then diffused inwards to increase nickel equivalent, resulting in fully austenitic phase. Cobalt-base

used for many years to produce surgical implant devices and is still widely used today in many applica-

To compare and understand the performance of the materials mentioned above, the metallic frame of a USB type C connector, as shown in Fig. 1, which is widely used in mobile phone and computer products, was used as the case study. Currently, 17-4PH is used as the material for the MIM frame of the USB Type C connector but, because of one of the specific requirements of the connector, wear resistance, a nitriding process is necessary. However, 17-4PH's martensitic structure sometimes changes to an expanded martensitic structure because of N inserted into the lattice of the martensitic structure if the nitriding temperature was not correctly controlled. If an expanded martensitic structure is formed after

“Currently, 17-4PH is used as the material for the MIM frame of the USB Type C connector but, because of one of the specific requirements of the connector, wear resistance, a nitriding process is necessary”

alloy implants can be conventionally manufactured by either wrought or cast techniques. The Co-Cr-Mo ASTM F75 (F75) standard has been widely

tions such as 3C components. Table 1 lists the advantages and material properties of 17-4PH, P.A.N.A.C.E.A. and F75.



Fig. 2 The MIM tensile bar

nitriding, the corrosion resistance of 17-4PH decreases sharply [3-9]. Therefore, an electroplating process was then needed for 17-4PH after nitriding to improve corrosion resistance and electrical conductivity. Because of the wear and corrosion resistance requirements of the USB connector, the fabrication process becomes very complex, resulting in a need for more production time, lowering production yield and increasing production cost. P.A.N.A.C.E.A. and F75 both have similar mechanical properties to 17-4PH and their wear and corrosion resistances are better than 17-4PH. Therefore, both materials might be the better choice for a USB connector application.

Experimental details

Feedstock and fabrication

The ready to use 17-4PH and P.A.N.A.C.E.A. feedstocks from BASF and Mitsubishi F75 powder mixed with UNEEC's own thermal binder, were chosen for this study. An Arburg injection machine (370S) was used to inject the tensile bars as shown in Fig. 2. The 17-4PH and P.A.N.A.C.E.A. samples were first catalytically debound and then sintered in a batch-type vacuum furnace. However, F75 has about 65% cobalt which will result in a dangerous substance, cobalt nitrate, when in a nitric acid atmosphere. Therefore, the F75 was debound in a thermal debinding furnace before sintering. The sintering profiles and conditions for the three MIM materials are shown in Fig. 3 and Table 2. For the sintered 17-4PH specimens, H900 and H1150 post heat treatment cycles were conducted to improve mechanical properties. For the P.A.N.A.C.E.A. sintered specimens, a post solution annealing step was conducted to totally dissolve chromium nitride (Cr_2N) precipitates into the austenite matrix and overpressure inert gas quenching was then applied with a cooling

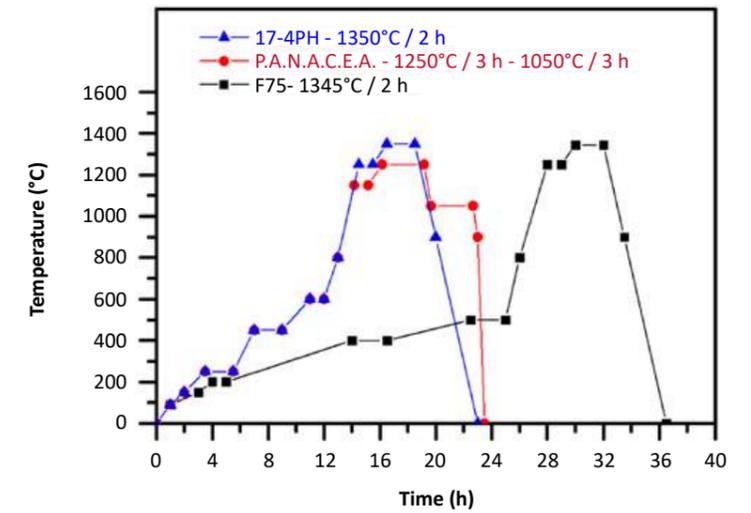


Fig. 3 Sintering profiles of 17-4PH, P.A.N.A.C.E.A. and F75

Materials	Atmosphere	Pressure
17-4PH	Ar	60 kPa
P.A.N.A.C.E.A.	N ₂	60 kPa
F75	N ₂	60 kPa

Table 2 The sintering conditions of 17-4PH, P.A.N.A.C.E.A. and F75

rate higher than 150°C/min to form the Cr_2N -free final parts for the assessment of corrosion resistance and toughness. For all 17-4PH and P.A.N.A.C.E.A. post-processed specimens, a 400°C/8 h plasma nitriding process was conducted to form a surface nitriding layer to improve wear resistance.

Material properties analysis

The composition analyses of the MIM sintered specimens were commissioned from SGS. Metallographic samples were polished and etched using 10 ml HNO_3 (98%) + 80 ml HCl (37%) at room temperature. The etching time was 20 s for 17-4PH, 2 min. for P.A.N.A.C.E.A. and 1 h for F75. The metallographic images of the specimens were observed by optical microscope (OLYMPUS, BX53M). Phase identification was performed by XRD (PANalytical, X'Pert PRO MPD). Field Emission Scanning Electron Microscopy (FESEM, JEOL, JSM-7800F Prime)

with EBSD detector (Oxford Instruments, NordlysNano) was applied for phase mapping analysis. Chemical compositions of specimens were characterised by EPMA (JEOL, JXA-8200SX) for elemental mapping. The densities of the MIM specimens were measured by specific gravity balance (SHIMADZU, AUJ 220). The hardness of the polished MIM specimens were measured by micro vickers hardness tester (SANPANY, MH-5L). The Yield Strength (YS), Ultimate Tensile Strength (UTS) and Elongation of the MIM specimens were measured by a universal testing machine (Linjie Technology, T20-SX). The relative magnetic permeability (μ_{rel}) of the MIM specimens were measured by permeability meter (Stefan Mayer Instruments, FERROMASTER).

For reliability tests, the wear resistance of the products was measured using a cycling test machine (MEIKO Instrument and equipment, MK-CB-5) with the criterion of wearing a depth of less than

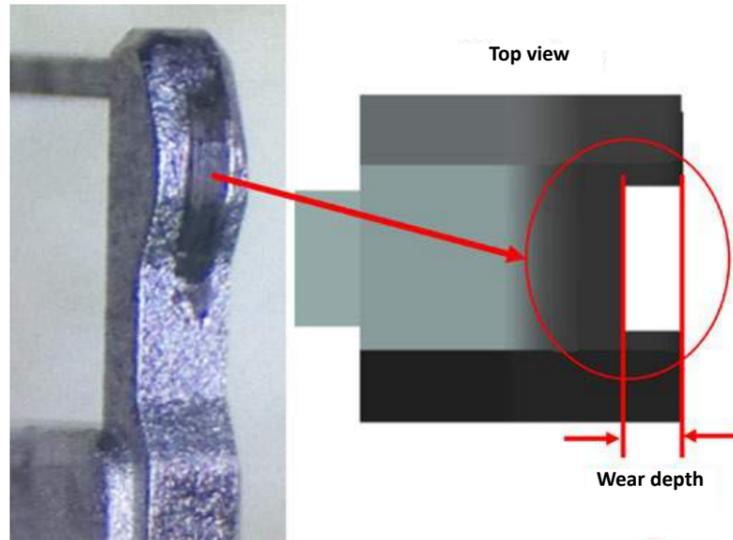


Fig. 4 Schematic diagram of wear and measurement test method

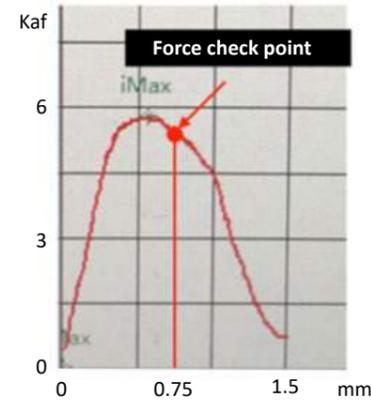


Fig. 5 Schematic diagram of the position to measure the bending force for the bending test

75 μm after 10,000 cycles [see schematic diagram in Fig. 4]. The bending force was measured using a bending test machine (LANWAN TESTING EQUIPMENT CO. LTD, 1220S). A bending force greater than 4 Kgf, with no breakage allowed at a displacement of 0.75 mm, were the criteria of the bending test, a schematic diagram of which is shown in Fig. 5. The corrosion resistance of products was measured using a salt spray test machine (CHUANG YU Instrument, CY-120CA) and the standard is not to rust after 48 h.

Results and discussions

Composition analysis

Table 3 lists the compositions of standard and MIM sintered 17-4PH, P.A.N.A.C.E.A., and F75 specimens. The test results show that all the constituent elements of the MIM sintered 17-4PH and F75 specimens meet the standard specifications. In the sintered P.A.N.A.C.E.A. specimen, however, all constituent elements also meet the standard specifications except

for nitrogen content. The response from the supplier was that a slight excess of nitrogen content is acceptable, but this should not exceed 1.01 wt.% so as not to affect the mechanical properties.

Microstructure analysis

Fig. 6 shows the metallographic structure of a sintered 17-4PH specimen before and after plasma nitriding. Both specimens show the standard 17-4PH metallographic structure (martensite and ferrite mixed phase) and the

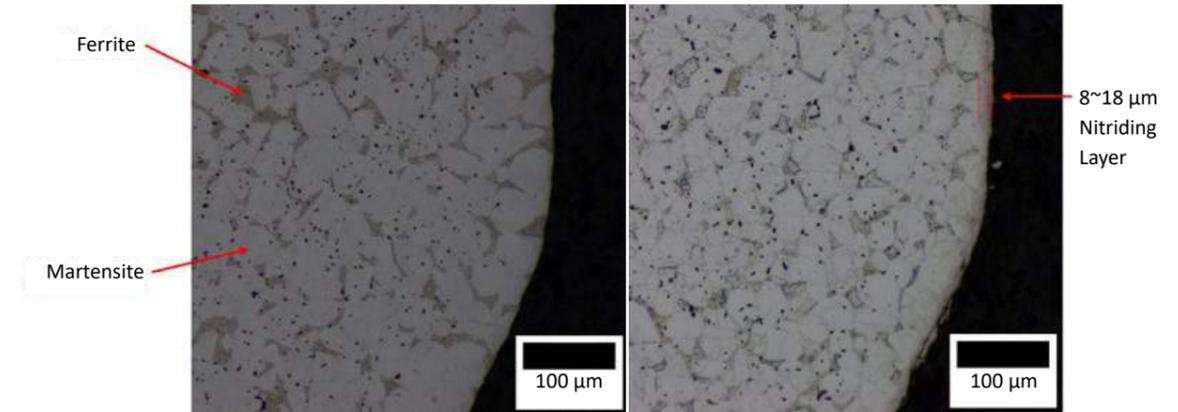


Fig. 6 The sintered 17-4PH specimen: (a) before and (b) after plasma nitriding

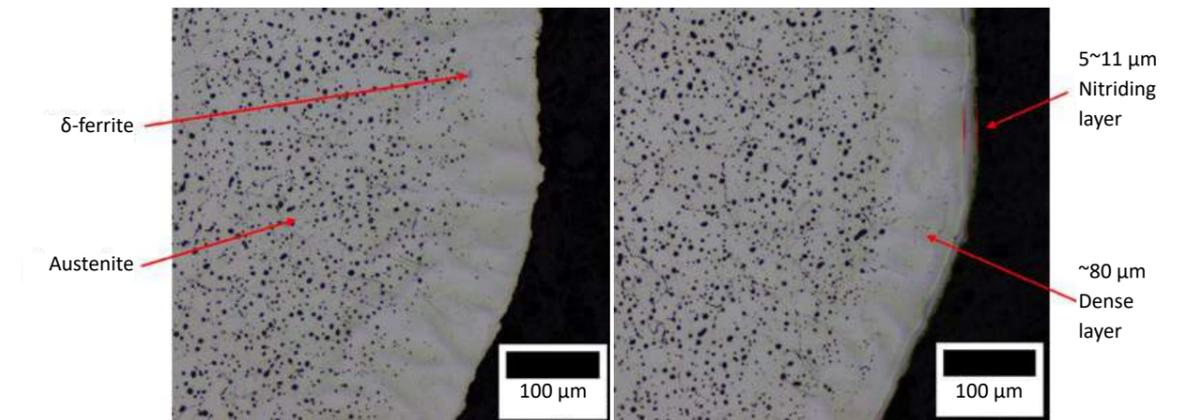


Fig. 7 The sintered P.A.N.A.C.E.A. specimen: (a) before and (b) after plasma nitriding

17-4PH	C	Si	Mn	Ni	S	P	Cr	Cu	Nb	Fe
Standard	≤ 0.07	≤ 1.00	≤ 1.00	3 ~ 5	≤ 0.03	≤ 0.04	15.5~17.5	3~5	0.15~0.45	Bal.
Sintered part	0.02	0.32	0.21	4.39	0.002	0.011	16.06	3.77	0.27	Bal.
P.A.N.A.C.E.A.	C	Si	Mn	Ni	Mo	N	Cr	Fe		
Standard	≤ 0.2	≤ 1.00	10 ~ 12	≤ 0.1	3.0~3.5	0.75~0.90	16.5~17.5	Bal.		
Sintered part	0.145	0.591	10.05	0.061	3.03	0.948	17.35	Bal.		
F75	C	Si	Mn	Ni	S	Fe	N	Mo	Cr	Co
Standard	< 0.35	< 1	< 1	< 0.5	< 0.01	< 0.75	< 0.25	5~7	27~30	Bal.
Sintered part	0.008	0.52	0.03	0.07	0.002	0.25	0.05	6.3	29.39	Bal.

Unit: wt.%

Table 3 The compositions of standard and MIM sintered 17-4PH, P.A.N.A.C.E.A. and F75 specimens

thickness of surface nitriding layer is about 8–18 μm .

Fig. 7 shows the metallographic structure of a sintered P.A.N.A.C.E.A. specimen before and after plasma nitriding. Both specimens show the standard P.A.N.A.C.E.A. metallographic structure (austenite phase, FCC) and the thickness of the surface nitriding layer is about 5 to 11 μm . A dense layer with very few pores and a thickness of about 80 μm is clearly seen near the outermost surface of the specimen, but it is not yet known what the formation mechanism is. A few small regions of δ -ferrite (BCC) formation were observed in the dense layer, and the EBSD results further showed that only δ -ferrite exists in the dense layer, as shown in Fig. 8.

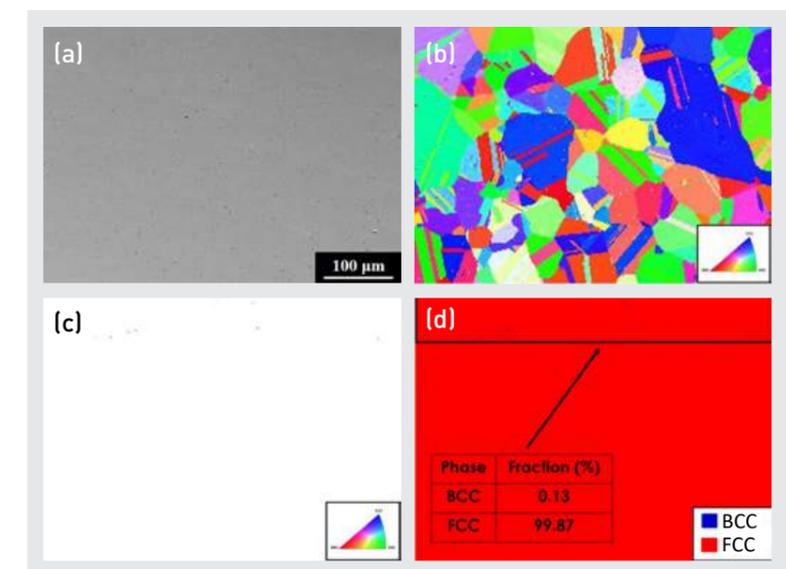


Fig. 8 EBSD results of outermost surface area for P.A.N.A.C.E.A. specimen: (a) SEM image, (b) FCC phase mapping, (c) BCC phase mapping, (d) BCC/FCC phase fraction comparison

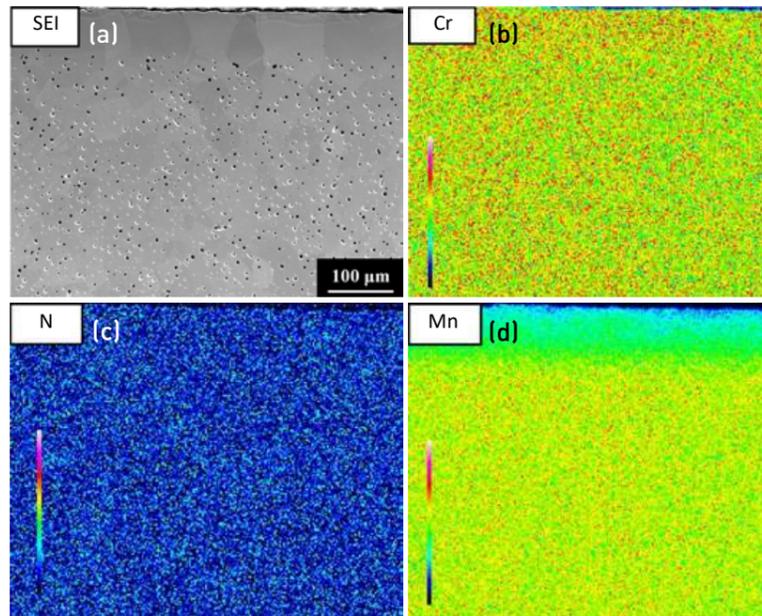


Fig. 9 EPMA mapping results of outermost surface area for P.A.N.A.C.E.A. specimen: (a) SEM image, (b) Cr element mapping of outermost surface area, (c) N element mapping of outermost surface area, (d) Mn element mapping of outermost surface area

Fig. 9 shows the results of EPMA elemental mapping, which verified the homogeneous distribution of N and Cr elements, whereas a significant amount of the Mn composition reduction phenomenon happens near the outermost surface of the MIM specimen, as shown in Fig. 9(d). After the quantitative

analysis, the concentration of Mn near the outermost surface was about 7.24 wt.%, and the internal concentration of Mn was about 11.56 wt.%. Due to the sublimation of Mn at relative low temperatures and its partial pressure reaching about 10^{-3} Pa at 700°C, further temperature

increases lead to higher Mn partial pressure [10-12]. In addition to the N, the Mn is also the stabilisation element for the austenite structure. Thus, the reduction of Mn will break the equilibrium state of austenite and a partial amount of the FCC austenite structure will transform into the BCC δ -ferrite to reestablish the equilibrium state. Therefore, it is reasonable that some δ -ferrite was observed in the dense layer. From EPMA mapping, it was found that the depth of the Mn-reduction area is similar to the thickness of the dense layer near the specimen's outermost surface. This may imply that the sublimation and evaporation phenomena of Mn are related to the formation of dense layer. In addition, the N concentration of P.A.N.A.C.E.A. itself is higher than 17-4PH, so the nitriding rate in the plasma nitriding process will be worse than 17-4PH. This will lead to the surface nitriding layer of P.A.N.A.C.E.A. being thinner than 17-4PH, but only by about 5–11 μ m.

Fig. 10 shows the metallographic structure of F75. Because of the excellent corrosion resistance of F75, no grain boundaries can be observed even after etching for 1 h. Therefore, the phase identification of F75 was performed by XRD and

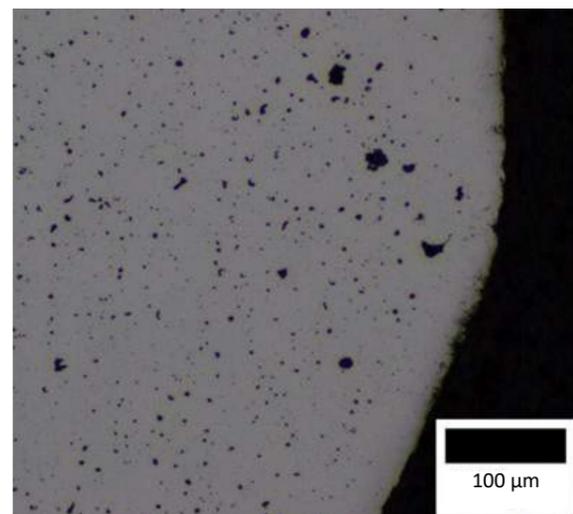


Fig. 10 The sintered F75 specimen without plasma nitriding specimen

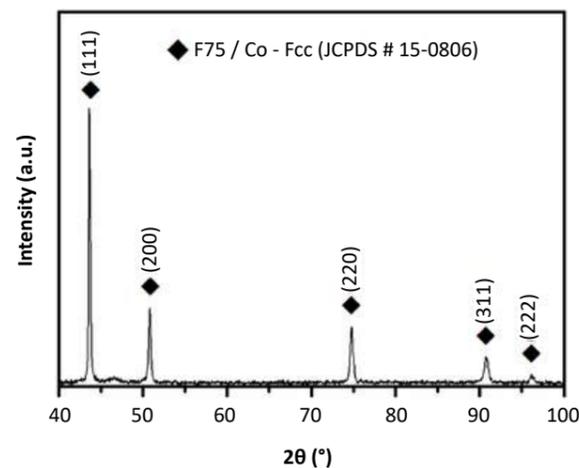


Fig. 11 The XRD pattern of F75 without plasma nitriding specimen

EBSD. The XRD pattern shows that F75 only has γ phase (FCC), as shown in Fig. 11. The EBSD results further confirm that F75 has γ phase only and the phase fraction of FCC is about 98%, as shown in Fig. 12.

Mechanical property analysis

Table 4 lists the densities of the 17-4PH specimens before and after plasma nitriding, the P.A.N.A.C.E.A. specimen before and after plasma nitriding, and the F75 specimen

without plasma nitriding. The relative densities of 17-4PH, P.A.N.A.C.E.A., and F75 are about 98%, 97% and 95% respectively. Table 5 lists the hardness of MIM specimens of 17-4PH before and after plasma nitriding,

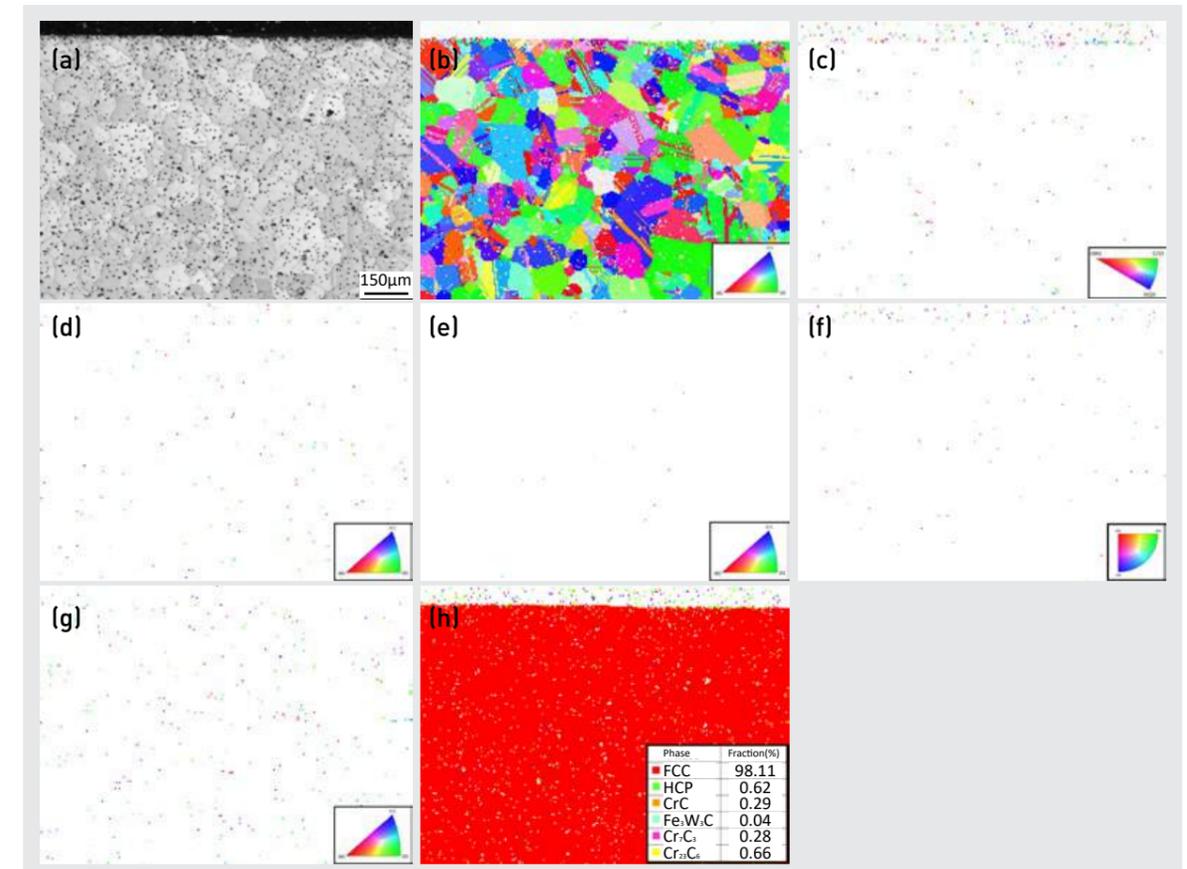


Fig. 12 EBSD results for F75 specimen: (a) SEM image, (b) FCC phase mapping, (c) HCP phase mapping, (d) CrC phase mapping, (e) Fe₃W₃C phase mapping, (f) Cr₇C₃ phase mapping, (g) Cr₂₃C₆ phase mapping, (h) Phase fraction comparison

Density (g/cm ³)	17-4PH	17-4PH + plasma nitriding	P.A.N.A.C.E.A.	P.A.N.A.C.E.A. + plasma nitriding	F75
AVE	7.654	7.650	7.605	7.600	7.857
Relative Density	~ 98%	~ 98%	~ 97%	~ 97%	~ 95%

Table 4 The densities of MIM specimens of 17-4PH and P.A.N.A.C.E.A. before and after plasma nitriding, and F75 without plasma nitriding

Hardness (HV)	17-4PH Centre	17-4PH + plasma nitriding		P.A.N.A.C.E.A.		P.A.N.A.C.E.A. + plasma nitriding			F75 Centre
		Centre	Nitriding layer	Centre	Dense layer	Centre	Dense layer	Nitriding layer	
AVE	286	393	948	299	271	302	283	903	286
Standard	17-4PH: \geq 280 HV, P.A.N.A.C.E.A.: 270–300 HV, F75: 266–345 HV								

Table 5 The hardness of MIM specimens of 17-4PH and P.A.N.A.C.E.A. before and after plasma nitriding, and F75 without plasma nitriding

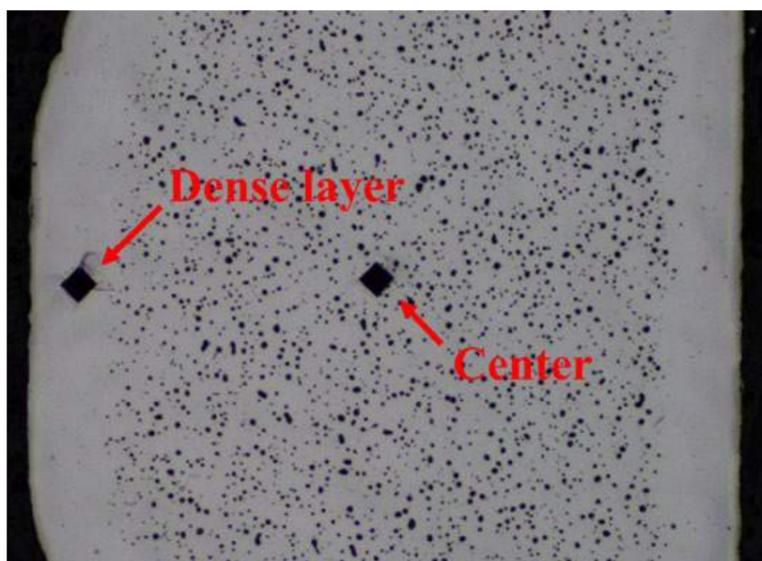


Fig. 13 The measurement positions of specimen for hardness test

P.A.N.A.C.E.A. before and after plasma nitriding and F75 without plasma nitriding. Fig. 13 shows the hardness measurement positions. The hardness of the centre of the 17-4PH specimen is 286 HV, but it increased to 393 HV after plasma nitriding due to N diffusion into the centre during plasma nitriding. The hardness of the surface nitriding layer of 17-4PH is 948 HV, as expected. The hardness of the centre of the P.A.N.A.C.E.A. specimen is 299 HV; however, the hardness in the dense layer is reduced to 271 HV. This is because the concentration of Mn in the dense layer is only half of the standard. Manganese is not only an austenite stabiliser for steel, but also enhances the hardening energy of steel. Therefore,

it is reasonable that the dense layer with lower manganese concentration has lower hardness. Comparing the hardness of P.A.N.A.C.E.A. before and after plasma nitriding, it was found that the hardness is slightly affected by the plasma nitriding process. This is also because P.A.N.A.C.E.A. itself has a relatively higher N concentration, which makes it difficult for N to diffuse into the centre during the plasma nitriding process. The hardness of the surface nitriding layer of P.A.N.A.C.E.A. is 903 HV, and the hardness of the centre of F75 is 286 HV. All specimen hardnesses meet their corresponding specifications.

Table 6 lists the Yield Strength, Ultimate Tensile Strength and Elongation of the 17-4PH specimen

Tensile Test	17-4PH	17-4PH + Plasma Nitriding	P.A.N.A.C.E.A.	P.A.N.A.C.E.A. + Plasma Nitriding	F75
YS [MPa]	793	-	699	704	590
UTS [MPa]	841	1063	1017	1017	954
Elongation [%]	8.4	3.6	40.2	40.2	21.4
Standard	17-4PH: YS ≥ 648MPa, UTS ≥ 792MPa, Elongation ≥ 6% P.A.N.A.C.E.A.: YS ≥ 670 MPa, UTS ≥ 960MPa, Elongation ≥ 35% F75: YS ≥ 450 MPa, UTS ≥ 655 MPa, Elongation ≥ 8%				

Table 6 The YS, UTS, and Elongation of MIM specimens of 17-4PH and P.A.N.A.C.E.A. before and after plasma nitriding, and F75 without plasma nitriding

before and after plasma nitriding, P.A.N.A.C.E.A. before and after plasma nitriding and F75 without plasma nitriding. The Yield Strength, Ultimate Tensile Strength and Elongation of the 17-4PH specimen before plasma nitriding, the P.A.N.A.C.E.A. specimen before and after plasma nitriding, and the F75 specimen without plasma nitriding meet their corresponding mechanical property specifications. However, the brittle fracture was observed in MIM 17-4PH after plasma nitriding specimens. This is because N diffuses into the centre position during the plasma nitriding process, making the specimen harder and more brittle. Besides, it is also observed that the plasma nitriding process has almost no effect on the Yield Strength, Ultimate Tensile Strength and Elongation of the P.A.N.A.C.E.A. specimens as P.A.N.A.C.E.A. itself has a relatively high N concentration.

Magnetic property analysis

Non-magnetism is one of the key properties of the P.A.N.A.C.E.A. and F75 materials. Therefore, it is necessary to measure the relative magnetic permeability of both MIM specimens. Table 7 lists the relative magnetic permeability of MIM specimens of P.A.N.A.C.E.A. before and after plasma nitriding and F75 without plasma nitriding. Based on the definition of SEW 390 (Stahl Eisen Werkstoffblatt), stainless steel could be classified as non-magnetic or paramagnetic once its relative magnetic permeability (μ_{rel}) is lower than 1.01.

The relative magnetic permeabilities of P.A.N.A.C.E.A. before plasma nitriding and F75 without plasma nitriding are 1.004 and 1.003, which meet the standard of non-magnetism. However, the relative magnetic permeability of P.A.N.A.C.E.A. after plasma nitriding exceeds the standard and increased from 1.004 to 1.017. It is now well established that nitrogen incorporation into the surface of austenitic stainless steels by various ion beam methods (ion beam implantation, plasma nitriding, etc.) at moderate substrate temperatures of about 400°C leads to a metastable, high nitrogen content phase, γ_N , in the surface treated layers [13–21]. High strength and enhanced wear resistance under high loads are a few important technological characteristics associated with the γ_N phase (also known as the expanded austenite phase or S phase) [15]. Another unusual but much less known and investigated characteristic of the γ_N phase is related to its magnetic nature. Depending on its nitrogen contents and associated lattice expansions, this phase is found to have ferromagnetic as well as paramagnetic characteristics. Previous low-energy, high-flux ion implantation research (via Mössbauer spectroscopy, MOKE and XRD) showed that the γ_N phase was ferromagnetically soft in nature, and was distributed in the highest nitrogen content region of the implantation treated layer [16]. The γ_N transformed to the paramagnetic state deeper into the layer as the nitrogen content and degree of lattice expansion decreased. The ferromagnetic γ_N is attributed to an FCC structure with nitrogen atoms in octahedral interstitial sites but with larger nitrogen contents than the paramagnetic γ_N phase [16]. The γ_N phase has been identified in the surface nitriding layer of P.A.N.A.C.E.A. specimen by XRD pattern as shown in Fig. 14, which is consistent with the results of Xiang-feng Zhang's research [21].

From the measurements and analyses above, it can be accepted that the material properties of all the specimens made by the defined

Relative Magnetic Permeability (μ_{rel})	P.A.N.A.C.E.A.	P.A.N.A.C.E.A. + Plasma Nitriding	F75
AVE	1.004	1.017	1.003
Standard	$\mu_{rel} \leq 1.01$		

Table 7 The relative magnetic permeability of MIM specimens of P.A.N.A.C.E.A. before and after plasma nitriding, and F75 without plasma nitriding

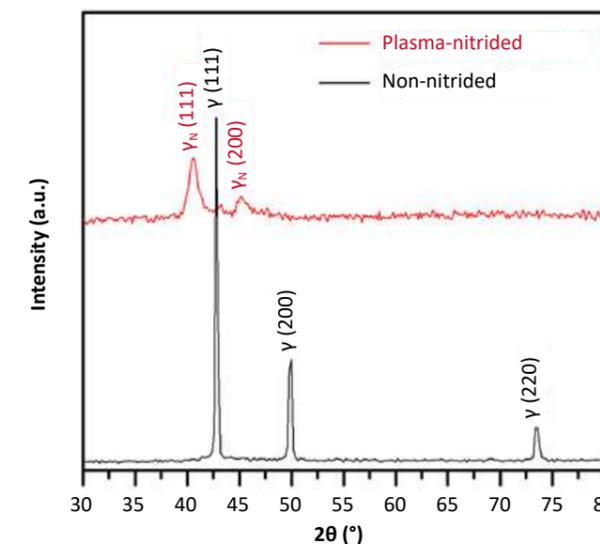


Fig. 14 The XRD pattern of surface nitriding layer of P.A.N.A.C.E.A. specimen

sintering profiles, conditions and post processes of each material can meet their corresponding standard specifications. Therefore, in the following case study, the sintering parameters and post processes corresponding to each material are applied to produce the MIM USB type-C connector frame.

Case study and reliability tests

The frame of the MIM USB type C connector used as the application for this case study requires good mechanical properties, good wear resistance, and good corrosion resistance. At present, 17-4PH is a popular MIM material for USB type C connectors due to its low cost. Apart from the basic MIM processes – injection, debinding, sintering and coining, post processes such as heat treatment, surface nitriding, and plating are usually adopted to enhance the strength and capabilities

of wear and corrosion resistances. Therefore, in this MIM USB connector application, the plasma nitriding process was used to improve the wear resistance, H1150 heat treatment was adopted to increase toughness, and a plating process was conducted to enhance the electrical conductivity and increase the corrosion resistance. The overall fabrication processes can therefore be complex and costly when MIM USB type C connector frames are made from 17-4PH.

From previous measurements and analysis results, the mechanical properties of both P.A.N.A.C.E.A. and F75 are also suitable for the USB connector applications. In the following sections, reliability tests such as cycling test, bending test, and salt spray test were defined to evaluate the performance, along with the cost of MIM USB connector frames made of P.A.N.A.C.E.A. and F75.

Depth (µm)	17-4PH	17-4PH + Plasma Nitriding	P.A.N.A.C.E.A.	P.A.N.A.C.E.A. + Plasma Nitriding	F75
Min.	160	8	17	7	5
Max.	346	16	36	12	25
Criteria	Wearing Depth < 75µm after 10000 cycles				

Table 8 The wearing depth of products of 17-4PH and P.A.N.A.C.E.A. before and after plasma nitriding, and F75 without plasma nitriding after 10,000 cycles

Bending Test	17-4PH + Plasma Nitriding	17-4PH + H1150 + Plasma Nitriding	P.A.N.A.C.E.A.	P.A.N.A.C.E.A. + Plasma Nitriding	F75
Force at 0.75 mm [Kgf]	-	5.28	4.14	4.29	5.43
Break Off	YES	NO	NO	NO	NO
Criteria	Bending force > 4 Kgf at 0.75 mm displacement and without breaking off				

Table 9 The bending force at 0.75 mm displacement and break check for products made of different materials with different post process conditions

Table 8 lists the wear depth of products of 17-4PH before and after plasma nitriding, P.A.N.A.C.E.A. before and after plasma nitriding, and F75 without plasma nitriding after 10,000 cycles. The wear depth of 17-4PH before plasma nitriding is 160–346 µm, reduced to 8–16 µm when plasma nitriding is applied. The wear depth of P.A.N.A.C.E.A. before plasma nitriding is 17–36 µm, reducing to 7–12 µm when plasma nitriding is applied. However, the wear depth of F75 is 5 to 25 µm without any post processing.

Table 9 lists the bending force at 0.75 mm displacement and breaking condition of products made of 17-4PH after plasma nitriding, 17-4PH with H1150 heat treatment and then plasma nitriding, P.A.N.A.C.E.A. before and after plasma nitriding,

and F75 without plasma nitriding. The products made of 17-4PH broke after the plasma nitriding process when force was applied as they became brittle. After H1150 heat treatment was applied prior to the plasma nitriding process, the toughness of 17-4PH products increased and the bending force reached 5.28 Kgf, without breaking. The bending force of P.A.N.A.C.E.A. before plasma nitriding is 4.14 Kgf, and 4.29 Kgf after plasma nitriding. The bending force of F75 without plasma nitriding is 5.43 Kgf.

Table 10 lists the salt spray test results of products made of 17-4PH before and after plasma nitriding, 17-4PH after plasma nitriding and then plating, P.A.N.A.C.E.A. before and after plasma nitriding, and F75 without plasma nitriding. The

products made of sintered 17-4PH can survive 48 h salt spray test; however, they corroded after 8 h salt spray test when plasma nitriding was applied. This is because of the Galvanic Effect [8]. It can be observed from the metallography of 17-4PH that the phase of the surface nitriding layer is different from that of the substrate. During the salt spray test, due to the potential difference between the surface nitriding layer and the substrate, galvanic corrosion occurred, which caused the product surface to be easily rusted. Therefore, the electroplating process is necessary for products made of 17-4PH after the plasma nitriding process in order to increase their corrosion resistance. The products made of P.A.N.A.C.E.A. before and after plasma nitriding and F75 without

Salt Spray Test (h)	17-4PH	17-4PH + Plasma Nitriding	17-4PH + Plasma Nitriding + Plating	P.A.N.A.C.E.A.	P.A.N.A.C.E.A. + Plasma Nitriding	F75
8	Pass	Fail	Pass	Pass	Pass	Pass
48	Pass	-	Pass	Pass	Pass	Pass
120	Pass	-	Pass	Pass	Pass	Pass
Criteria	48 h without rust					

Table 10 The salt spray test results of products made of different materials with different post process conditions

Materials & Process	Raw Material (Feedstock)	H1150	Quenching	Plasma Nitriding	Plating	Cost
17-4PH	100%	✓		✓	✓	100%
P.A.N.A.C.E.A.	290%		✓		✓	109%
P.A.N.A.C.E.A.	290%		✓			61%
F75	463%				✓	87%
F75	463%					40%
Remark:	The price of raw material and current fabrication process of 17-4PH is used as a benchmark and the cost is 100%.					

Table 11 The comparison of product cost versus production processes

plasma nitriding all meet the salt spray test criteria without plating. This is because both P.A.N.A.C.E.A. and F75 have an FCC structure with very good corrosion resistance.

From the three reliability test results above, it was found that products made of P.A.N.A.C.E.A. do not require a plasma nitriding process to meet the product reliability test criteria. Therefore, in the following fabrication process and cost comparison, the plasma nitriding process will not be included for products made of P.A.N.A.C.E.A..

Table 11 lists the raw material price of each material and the cost of the product's corresponding fabrication process. The current 17-4PH fabrication process is used as a benchmark and the cost is 100%. Although the price of the raw material of P.A.N.A.C.E.A. and F75 are three times and four and a half times higher than 17-4PH, products made of P.A.N.A.C.E.A. require two post processes, quenching and plating, so, the production cost will be 9% higher than 17-4PH. If product is made of F75 with a plating process (for the purpose of electrical conductivity), the cost can be reduced by 13% compared to 17-4PH. If the product does not require electrical conductivity and the plating cost is removed, the production cost of using P.A.N.A.C.E.A. and F75 materials can further be reduced by 39% and 60% respectively compared to 17-4PH.

From this case study, it can be concluded that if the right materials

were selected during the product development stage, benefits such as simplifying fabrication process, shortening the production lead time and lowering the production cost can be achieved.

Conclusion

The material properties of MIM products in the communication and electronics industry are becoming more and more demanding. Therefore, when developing MIM products, it is important to understand the impact of various materials on their production costs and performance. From the case study in this research, the benefits of choosing the right material in an early stage of a product's development have been demonstrated. The comparison trends and conclusions in this study might not be fully applicable to all MIM applications, due to differences in powder types, solid loading, binder types, part weight, etc., but provide the appropriate directions to pursue.

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Authors

Shin Lee, Chung-Huei Chueh and I-Shiuan Chen
Chenming Electronic Tech. Corp. (UNECC)
Taiwan
tim_lee@tw.unecc.com
www.unecc.com

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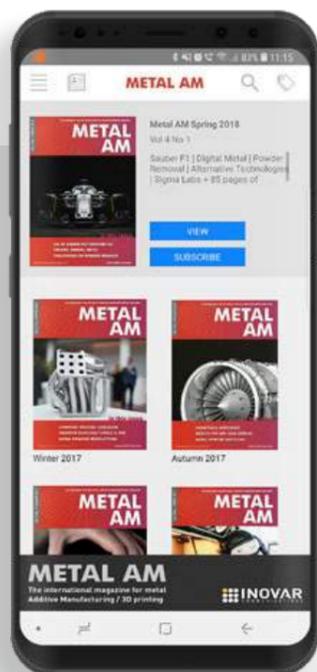
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The production and evaluation of alumina sinter supports for Metal Injection Moulding by ceramic Additive Manufacturing

In this article, Dr Samuel von Karsa-Wilberforce, Emery Oleochemicals GmbH, Germany, and co-authors report on the production and evaluation of sinter supports for Metal Injection Moulding produced by the Additive Manufacturing of highly filled alumina feedstock filaments. The alumina filaments are based on Emery Oleochemicals' established PIM binder system and processed by Material Extrusion (MEX). Partners in the study include CMG Technologies, UK, 3DGence Sp. z o.o, Poland, Spectrum Filaments, Poland, SiCeram GmbH, Germany, and Ingenieur-Buero Jaeckel, Germany.

Material Extrusion (MEX), the ISO category for AM processes that are also known as Fused Filament Fabrication (FFF) or Fused Deposition Modelling (FDM), is evolving into a very cost-efficient technology for the production of metal and ceramic parts using sinterable filaments. This is particularly the case when compared with more widely known metal AM processes such as Laser Beam Powder Bed Fusion (LB-PBF) where, apart from the cost-efficiency advantage of additively manufacturing with sinterable feedstock filaments, the processing of ceramic materials using a process such as LB-PBF is simply not possible. Additionally, standard sinterable powders can be used in sinter-based AM processes as powder flow properties are not as critical as in LB-PBF. As with any other AM process, the selection of the right application is crucial to the successful use of sinterable feedstock filaments.

This study seeks to compare the performance of additively manu-

factured alumina sinter supports produced by MEX with state-of-the-art sinter supports manufactured by Ceramic Injection Moulding (CIM). Sinter supports, produced by the extrusion of sinterable feedstock filaments, have the potential to be used for small series runs of components usually manufactured by Metal Injection Moulding (MIM) (Fig. 1).

Material Extrusion process overview

Material Extrusion has been used for the processing of thermoplastic polymeric materials for a number of decades. One of the first main applications of MEX was in rapid prototyping, where it offered the

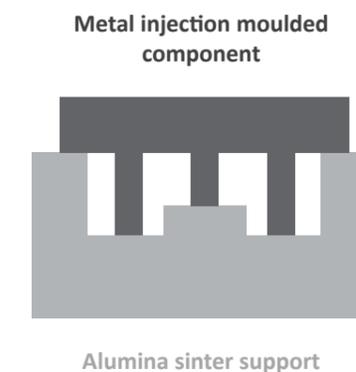


Fig. 1 Schematic of sinter support and MIM component

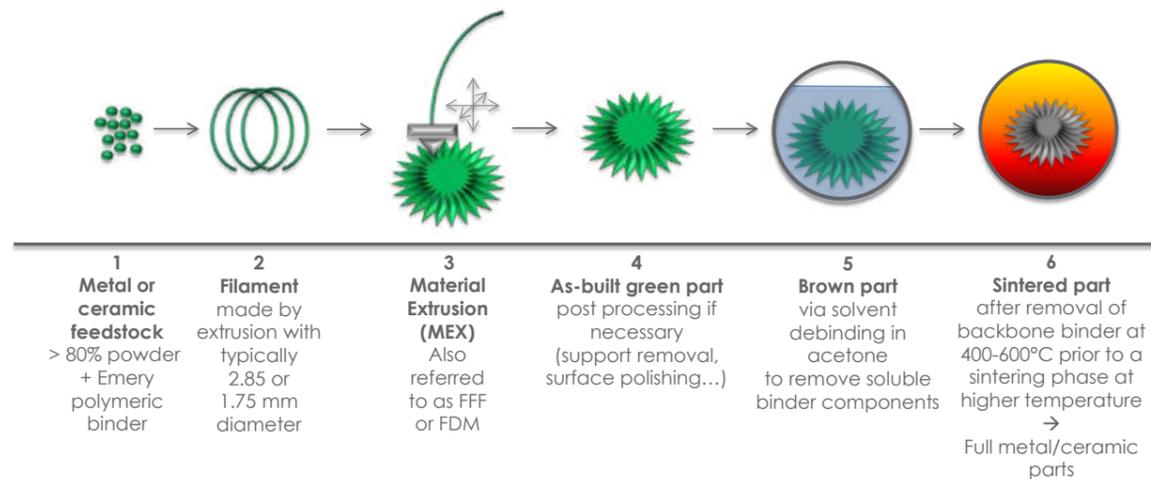


Fig. 2 Illustration of AM process used, from raw material to sintered part

benefits of reduced cost as well as faster time-to-market. Across all material types, MEX is today the most widely used of all AM technologies, due to its suitability for commercial and home use, as well as the ease of operation of MEX machines compared with other AM technologies [1]. The result of this is the increasing availability of new materials for MEX, including

'feedstock filament' is an evolution of conventional Powder Injection Moulding feedstock, which is used in a granulated form.

These highly filled feedstock filaments can be processed in the same way as conventional thermoplastic filaments. However, after a build, the additively manufactured part, known as a 'green' part, is not yet functional and has to go through post-

The promising technological attributes of extrusion-based metal and ceramic AM, such as user-friendliness, the simplicity of the technology and the ability to use standard sinterable PIM powders as flow properties are not critical, led to the adaptation of the well-established PIM binder system from Emery Oleochemicals for metal and ceramic filaments. Metal and ceramic parts produced with filaments based on the Emery binder system typically have very high green part strength, allowing them to be handled and transported with ease, as well as the ability to apply processes such as polishing.

Despite the promising use of metal and ceramic based filaments, the selection of the right application is key to the realisation of the full potential of the technology, as well as for customer satisfaction. Others have investigated the use of metal and ceramic feedstock extrusion for cutting tools and magnetic material applications [3]. This article will therefore focus on the Additive Manufacturing of sinter supports for MIM components, employing ceramic feedstock filament based on Emery Oleochemicals' binder technology.

high-performance polymers such as polyetheretherketone (PEEK), as well as, more recently, highly filled polymeric filaments containing metal or ceramic powders, typically up to > 80 wt.%. Within the filament, the powder particles are held together by a thermoplastic binder. Such a

processing steps to achieve its final form as a metal or ceramic part. The complete process is outlined in Fig. 2. It is worth mentioning that although a solvent debinding system is used in this example, catalytic or thermal debinding systems also exist.



Fig. 3 A spool with aluminium oxide filament, 2.85 mm thickness

The production of MIM sinter supports via current processes, most commonly machining and Ceramic Injection Moulding, can result in long lead times for the production of MIM components. Delivery times for the moulds to make the supports by CIM, as well as the time required for mould optimisation, may be in the region of eight weeks. Hence, the Additive Manufacturing of sinter supports using ceramic feedstock filaments enables the rapid and on-demand production of sinter supports, leading to short lead times and a shorter time to market. It should also be considered that current production methods for ceramic sinter supports add a significant overhead cost to MIM component production [4]; therefore, a more efficient way to manufacture sinter supports will be advantageous for the MIM industry.

The alumina sinter supports produced for this case study were used for a commercially manufactured MIM component produced by CMG Technologies, a well-established MIM company based in the UK. The digital file from which the sinter supports were built was provided by CMG, which also tested the finished sintered alumina sinter supports with the corresponding MIM parts and CIM sinter supports as reference.

Production of alumina feedstock filament

The alumina feedstock granules were compounded by SiCeram GmbH, Jena, Germany, using 99.7% pure alumina powder with a particle size D50 of approximately 0.6 µm and the binder system from Emery Oleochemicals. The binder system mainly consisted of the LOXIOL® 2472 plasticiser produced exclusively by Emery Oleochemicals and a polyamide copolymer. The compounded alumina feedstock granules contained approximately 80 wt.% alumina powder. The feedstock granules were then supplied

to Spectrum Filaments, Poland, to produce the alumina feedstock filaments. Spectrum Filaments, an established manufacturer of filaments for Additive Manufacturing, extruded the 2.85 mm diameter feedstock filaments using a single screw system (Fig. 3). The green density of the alumina feedstock filament was 2.53 g/cm³.

During filament production, the diameter was measured every 1 mm in 2 axes with ± 0.8 µm accuracy. To be sure that the measurement results are reliable, Spectrum Filaments uses certified laser measuring devices. In the final step, the collected data are digitally stored by Spectrum Filaments, enabling customers and end-users to check the filament diameter online.

Additive Manufacturing of alumina MIM sinter supports

CMG Technologies supplied the STL file for the sinter support. In order to obtain near-final dimensions of the sinter supports after the final post-processing step, the STL file of the sinter support was modified using Cura Additive Manufacturing software to compensate for shrinkage after sintering of approximately 19–21% in xyz directions. After this, the input file for the AM machine, known as

the g-code file, was generated. The g-code file tells the AM machine what actions to perform to build the part. Two different machines were used to build the sinter supports, with the first being a BCN3D Sigma r19 machine from BCN3D Technologies, Spain. This is a standard filament system available on the open market and suitable for developmental work and proof of concepts. The second system was a high-performance machine with a modified print head from 3DGence, Poland, for the processing of sinterable feedstock filaments and designed for small series production. The build parameters used on both machines were as follows:

- Build temperature of between 160–170°C
- Build speed of between 20–50 mm/s,
- Extrusion head nozzle diameter of between 0.4–0.6 mm
- Layer height of 0.1 mm
- Infill density of 30%

A total of approximately twenty sinter supports were built for post-processing and application testing (Fig. 4). Sinter-supports with both opened-bottom grid structure and closed-bottom grid structure were built to investigate the effect on their application as MIM sinter supports (Fig. 5).

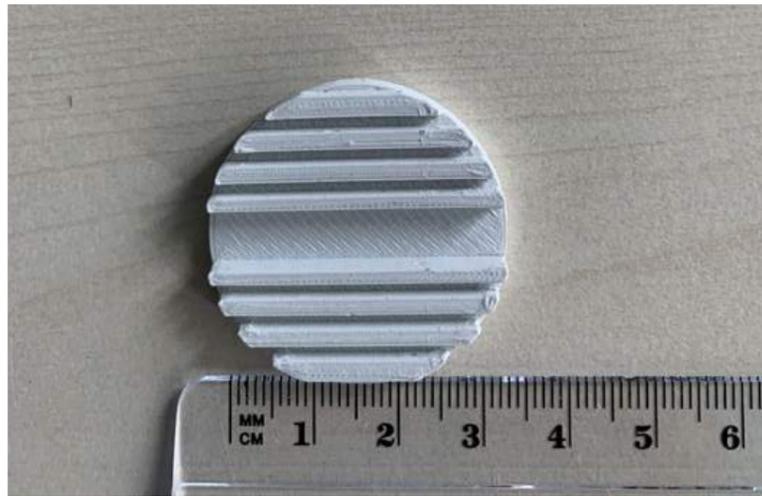


Fig. 4 An example of an additively manufactured green alumina sinter support with 30% infill density

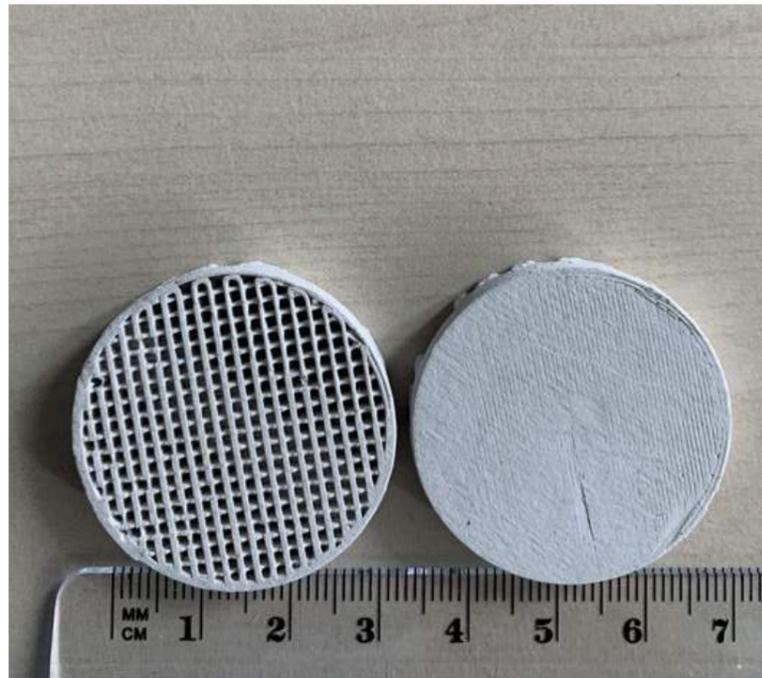


Fig. 5 Examples of green AM alumina sinter supports with opened-bottom grid base and closed-bottom base but with grid infill structure. Both supports have infill density of 30%

Post-processing of alumina sinter supports

The solvent debinding and sintering of the green sinter supports were carried out by SiCeram GmbH. Solvent debinding of the sinter

supports was carried out in acetone at 42°C for approximately twenty-four hours, followed by a 3–5 hour drying time at room temperature to remove the residual acetone. The remaining backbone polymeric binder component was removed at 500–600°C during pre-sintering at 1250°C in

air to obtain partially sintered supports. The pre-sintering of the sinter supports allowed for a much better control of part deformation and twisting that might occur during sintering. The final sintering of the supports was carried out at 1540°C in air to obtain the fully sintered alumina supports (Fig. 6).

Application testing of final sinter supports with MIM component

The flatness, surface roughness, height and diameter of the fully sintered sinter supports are crucial for the successful use of the supports. The flatness of the supports was determined via the so-called rock test using a digital height gauge. The rock test flatness values were all below 0.1 mm, indicating good flatness for use as sinter supports. Typically, rock test flatness values of sinter supports above 0.15 mm render them unusable.

The average surface roughness of the additively manufactured sinter supports was measured to be between 2.0–2.5 µm Ra and this was higher than that of sinter supports manufactured by CIM, which had a surface roughness of approximately 0.3 µm Ra. The surface roughness value of the AM sinter supports was, however, well below the 5 µm Ra maximum surface roughness for such an application. Sinter supports with a surface roughness above 5 µm will most likely cause markings on the surface of the MIM components, rendering them unusable.

The average final dimensions of height and diameter of the AM sinter supports were measured to be approximately 4.33 mm and 28.54 mm, respectively. The height and diameter measurements were close enough to the theoretical dimensions of height and diameter (4.5 mm and 29 mm, respectively), indicating sufficient accuracy to produce sinter supports for MIM applications.

It is worth mentioning that this is an initial proof of concept for the accuracy of the MEX process for the production of alumina sinter supports. The flatness, roughness and dimensional accuracy can still be further optimised to meet the needs of the user.

The AM alumina sinter supports were then tested in use as supports for the specific MIM application at CMG, with the MIM parts positioned on the AM sinter supports and sintered at 1300°C (Fig. 7). The results showed that the AM alumina sinter supports performed as well as the CIM alumina sinter supports.

In addition, high-performance lightweight alumina sinter supports could be produced by AM with an infill density of 30%, leading to material savings, lower production costs and energy savings during sintering. For the sinter support geometry and size considered in this case study, the base structure (whether opened-based grid or closed-based grid) had no effect on the function as sinter supports. Nonetheless, having an opened-base grid structure could lead to quicker solvent debinding when manufacturing the supports.

The reuse attributes of the sinter supports were also investigated for approximately seven days, based on two sintering cycles a day at 1300°C. After approximately fourteen sintering cycles, the sinter supports showed no visual surface, structural or material degradation, confirming their durability (Fig. 8). The strength of the supports also appeared to be unchanged after the fourteen runs.

Conclusion

In this study, ceramic feedstock filaments were employed to produce high-performance MIM sinter supports with excellent reuse attributes. The targeted control of the infill density at 30% of the AM alumina sinter supports allowed the production of lightweight high-performance MIM sinter supports with excellent durability and shock resistance, which is sometimes poor



Fig. 6 Fully sintered AM alumina sinter supports. Full sintering was carried out at 1540°C in air

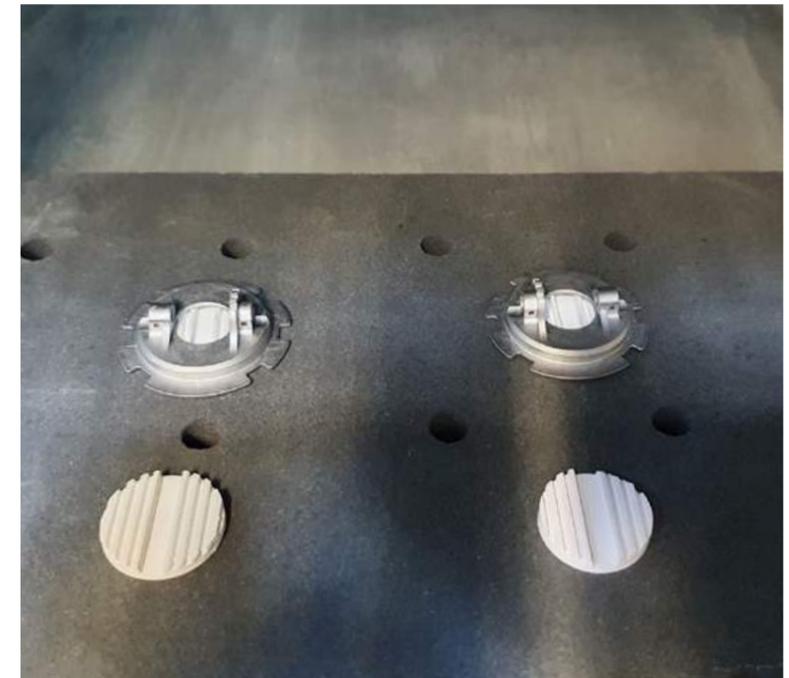


Fig. 7 Photo of MIM components sitting on an AM sinter support (left) and Ceramic Injection Moulded sinter support (right) in a sintering furnace

with fully dense supports. Moreover, as a result of targeted control of the infill density of the sinter supports, savings on material, production time and costs were achieved. The production of MIM sinter supports via filament-based Additive Manufacturing provides a cost-effective solu-

tion to the challenge of producing sinter supports on-demand, reducing time-to-customer and time-to-market.

Additionally, production of sinter supports via this process is ideal for small series component production where a new mould is needed

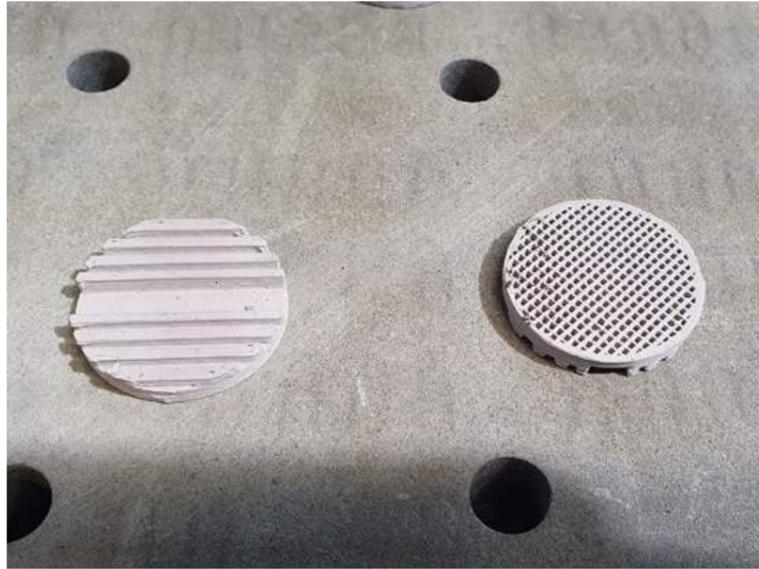


Fig. 8 Sinter supports after approximately fourteen sintering cycles at 1300°C. No visual degradation to surface, structure or material was observed

for each small series component, leading to significantly higher overall production costs. Furthermore, the outsourcing of sinter support moulding could result in lead times of up to eight weeks, leading to delay in final MIM component production.

Whilst it was shown that the AM sinter supports could be reused over a limited period, the long-term reuse attributes of the AM alumina sinter supports need to be further investigated. Furthermore, other MIM sinter support geometries, as well as supports with larger dimensions, need to be manufactured and tested. This will enable the evaluation of the impact of using MEX technology to manufacture different support geometries and sizes.

Authors

Dr Samuel von Karsa-Wilberforce¹,
Dr Christian Müller¹, Dr Albert
Kerber², Manfred Jaeckel³, Phil
Grimmer⁴, Filip Turzynski⁵

¹Emery Oleochemicals GmbH, Paul-
Thomas-Strasse 56
40599 Dusseldorf
Germany

samuel.wilberforce@emeryoleo.com,
christian.mueller@emeryoleo.com

²SiCeram GmbH
Am Naßtal 10
07751 Jena
Germany
a.kerber@jsj.de

³Ingenieur-Buero Jaeckel
Memeler Strasse 29
27612 Loxstedt
Germany
manfred.jaeckel@t-online.de

⁴CMG Technologies
Unit 11, Thompson Drive
Base Business Park
Rendlesham,
Woodbridge IP12 2TZ
UK
pgrimmer@cmgtechnologies.co.uk

⁵3DGence Sp. z o.o.
Przyszwice Office
ul. Graniczna 66
44-178 Przyszwice
Poland
filip.turzynski@3dgence.com

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