VOL. 9 NO. 4
WINTER 2020

POWDER METALLURGY REVIEW

ATOMISATION AT ARCAST

DYNAMIC IMAGE ANALYSIS & LASER DIFFRACTION

SURFACE AREA IN POWDER CHARACTERISATION

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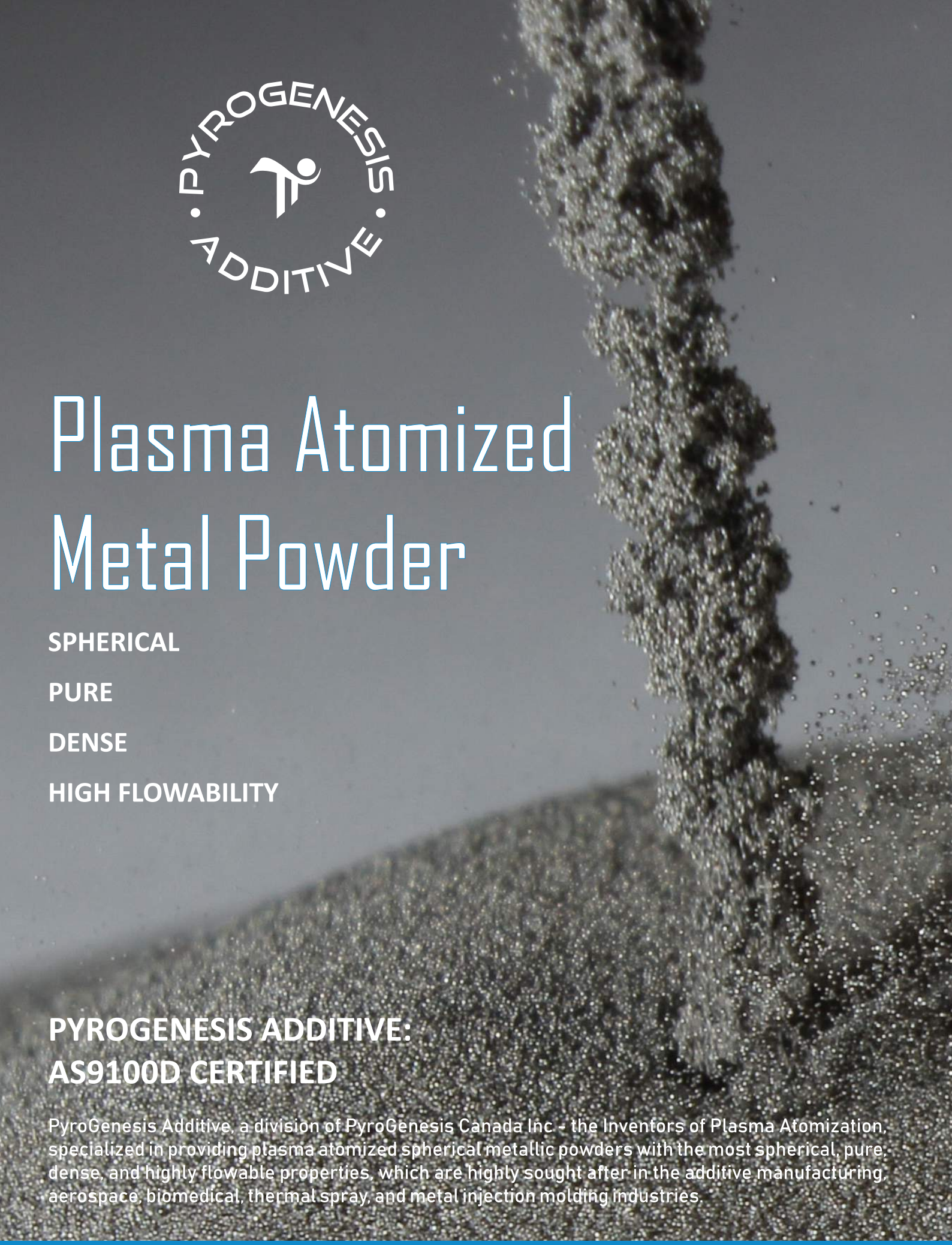

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A focus on metal powder

To say this year has been like no other would be an understatement, with the coronavirus pandemic impacting all sectors of society and industry. Although travel and exhibitions have been hit hard, the virtual conferences that have resulted have been a great success. While the associated networking and social aspects may be missing, the actual presentations and Q&A sessions have translated very well to the digital format.

This was evident in the EPMA's Euro PM2020 Virtual Congress, which replaced its popular annual gathering this year. Three days of technical presentations and special interest seminars, with lively Q&A discussions following each session, were attended by over 270 participants from around the world.

In this issue of *PM Review*, we report on a number of presentations from the event which highlighted functional materials in energy management and magnetic applications, areas that could open new opportunities for Powder Metallurgy in the future.

We also have a special focus on metal powders. We discover how Arcast has developed its compact, lab-sized atomisers and moved into larger-scale systems, and explore the benefits of dynamic image analysis and laser diffraction for particle characterisation, as well as how understanding the surface area of a powder particle is a critical parameter for successful Additive Manufacturing.

Paul Whittaker
Editor, *Powder Metallurgy Review*

Cover image
Induction drip melting atomisation at Arcast (Courtesy Arcast)

We are in unprecedented times. However, these are the times when agility, resilience and innovation of our people define our businesses.

At Rio Tinto Metal Powders we have implemented social distancing measures, promoted good hygiene habits and applied new site access requirements including body temperature measurements. Furthermore, at our Technology Centre in Sorel-Tracy, we produced hand sanitizer to keep our employees and communities' safe – even supplying paramedics. We also donated hundreds of N95 (FFP2) masks to the local hospital.

These initiatives make Rio Tinto a part of the solution in the fight against COVID-19. If you are proud of your initiatives, share with us and we will publish them in our next Customer Bulletin. We are all in this together, and it is through teamwork and innovation that we will rise to the challenge. Please feel free to contact your regional sales representative should you have any concerns during the COVID-19 crisis or email us at **info.qmp@riotinto.com**

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POWDER METALLURGY REVIEW


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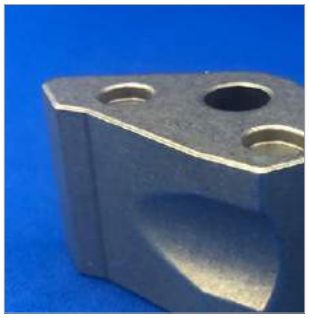
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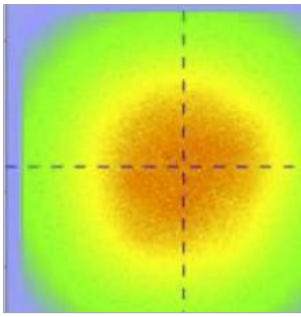
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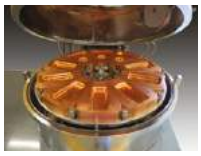

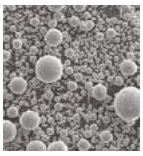

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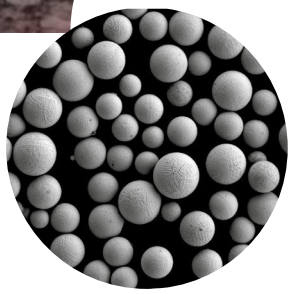

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industry news

To submit news for inclusion in *Powder Metallurgy Review* contact Paul Whittaker, paul@inovar-communications.com

SMS group to supply Outokumpu's new stainless steel powder atomisation plant under subscription contract

SMS group, Düsseldorf, Germany, reports that it is to supply global stainless steels manufacturer, Outokumpu, headquartered in Helsinki, Finland, with an atomisation plant through a new subscription contract. The atomisation facility will be used for the production of high-quality stainless steel powder used in Additive Manufacturing.

SMS group states that this is the first ever facility the group will have supplied under a subscription contract, with the agreement reportedly being new territory for both companies. It is hoped it will lead to long-term cooperation between the companies. The subscription contract is a business model under which the group will remain the owner of the powder atomisation plant, while Outokumpu will be the operator of the plant. Outokumpu will pay SMS group pro rata of the quantity of stainless steel powder produced.

The powder atomisation plant will include an induction melter, atomiser, two cyclones and filter elements, and will be designed to allow the complete process to take place in an inert atmosphere. This enables temperature measurements, sample taking and material feeding to be performed without causing any atmospheric variations.

SMS group will supply Outokumpu with an atomisation plant through a subscription contract (Courtesy SMS group)

The atomisation plant is scheduled to become operational in early 2022, and will aim for an annual production of up to 330 tons of stainless steel powder.

"Right from the beginning the whole project has been sailing under the flag of partnership," stated Tobias Brune, SMS group Head of Additive Manufacturing & Powder Metallurgy.

"With this performance-based contract model we, as Leading Partner in the World of Metals, are breaking new ground jointly with our customer which will bring both of us forward. The subscription contract provides for both companies to concentrate on their respective core competencies to be successful in the market."

Philip Salfeld, Outokumpu's Manager Strategic Investments, commented, "As the inventors of stainless steel, we are aiming to continuously advance innovation in general, and the development and distribution of this highly versatile and sustainable material. In so doing, we are always looking out for innovative applications that will attract new customer segments to our products. Metal powder is one such innovative business field, and we are looking very much forward to developing it jointly with SMS group."

www.sms-group.com
www.outokumpu.com

Sandvik increases focus on digital solutions in business reorganisation

Sweden's Sandvik AB is reorganising its tool business to further strengthen its position within future digital solutions, also known as Industry 4.0, explains Stefan Widing, CEO of Sandvik. According to Widing, the smart factory is the heart of Industry 4.0., therefore Sandvik is carrying out a reorganisation with the aim of expanding digital technology to help make customers more productive and sustainable. With this in mind, Sandvik Machining Solutions, the business area for metal-cutting processing, has changed its name to Sandvik Manufacturing and Machining Solutions, and has been divided into two separate business area segments: Sandvik Machining Solutions and Sandvik Manufacturing Solutions.

Stefan Widing, president and CEO of Sandvik (Courtesy Sandvik)

The Sandvik Machining Solutions business segment includes the traditional tool business and brands such as Sandvik Coromant, Walter, Wolfram, Seco and Dormer Pramet. Sandvik Manufacturing Solutions will reportedly focus on related technologies and digital solutions, including the divisions for Metrology, Additive Manufacturing and Design and Planning Automation. These technology areas are expected to grow strongly, with the current providers of these services often not being Sandvik's existing competitors, states the group.

"One of the purposes of the reorganisation is to create new business opportunities," commented Widing. "The new Sandvik Manufacturing Solutions segment strengthens our position within digital manufacturing and contributes to our market-leading position. These areas need a dedicated focus and to some extent a different direction. They are often smaller, with characteristics of software companies, rather than the manufacturing industry. To run them successfully, a different governance model is required."

Widing will lead Sandvik Manufacturing Solutions for a year, starting on January 1, 2021, in parallel with his role as CEO. He added, "This is because it is a very important area for the future. It is broad and complex and will require investments through acquisitions in areas such as metrology, planning tools, tool data management and 3D printing. If and when we find the right company, we must be able to act quickly."

Additionally, digitisation continues to be a focus area for the core business. Widing further added, "Our core business in metal cutting is on a journey from only providing tools to providing complete solutions, including everything from sensors and connected tools that exchange data via the cloud to digitised planning tools."

Digitisation means that experiences and knowledge from manufacturing are shared in real-time, both internally and externally and between people and machines. The growth ambitions in the digital area are said to be high, within both Sandvik Manufacturing Solutions and Sandvik Machining Solutions. The 2025 target for the business area segments is to have total sales of SEK 5 billion connected to digital solutions and services.

www.home.sandvik

Umicore to streamline its Cobalt & Specialty Materials activities

Umicore, a global materials technology and recycling group headquartered in Brussels, Belgium, has reported that, as part of the ongoing reassessment of its global production footprint, it plans to streamline its cobalt activities in the business unit Cobalt & Specialty Materials, with the aim of strengthening the business unit's competitive position.

Cobalt & Specialty Materials is focussed on the refining, production and distribution of cobalt and nickel speciality chemicals for a wide range of non-battery related applications, including Powder Metallurgy. Over the past few years, the business unit is reported to have been facing increasing competition in several of its end-markets, and more recently in its cobalt refining activities, due to the emergence of large-scale cobalt refineries. Against this backdrop, Umicore has announced plans to consolidate part of the business unit's core activities in Kokkola, Finland and Nashville, Tennessee, USA, in order to achieve synergies and strengthen the unit's competitive position.

According to this plan, the cobalt refining and part of the cobalt transformation activities of the Olen plant in Belgium will be moved to the recently acquired Kokkola refinery in Finland. This refinery is one of the largest cobalt refineries globally, and allows the business unit to produce at larger and more competitive scale. The transfer of activities is expected to be finalised by mid-2023 and will entail a reduction of 165 positions in Olen through natural attrition.

In the US, the business unit will discontinue operations in Arab, Alabama, and consolidate activities in its plant in Nashville, Tennessee. Earlier in the year, the business unit also closed its cobalt, nickel and rhenium refining and recycling plant in Wickliffe, Ohio.

www.umicore.com

Höganäs launches Vacuum Induction Gas Atomiser plant at Laufenburg site

Sweden's Höganäs AB has launched its new Vacuum Induction Gas Atomiser (VIGA) at its site in Laufenburg, Germany, where the company produces metal powders for Additive Manufacturing. The company states that the VIGA system, which was commissioned in August after a few turbulent months during the coronavirus (COVID-19) pandemic, represents how Höganäs is setting new standards for powder quality, as well as for workplace conditions.

"With the VIGA, we are setting new standards on a number of levels," stated Daniel Reimann, Production Manager at the Höganäs Laufenburg site. "On the one hand, we are using it to produce metal powder of even higher quality than before; while on the other, we are also ensuring workplace conditions of the highest standard."

In addition to powder quality, the working conditions and organisational processes surrounding its production are said to also raise the standards at Höganäs to a new level.

"Product quality and workplace quality go hand in hand," continued Reimann. "So, it was important to come up with a solution for the design of workplaces where staff feel comfortable and can concentrate on their tasks. For instance, this includes consideration of the fact that it is more pleasant for staff to monitor the melting and atomisation process from an air-conditioned control room, rather than standing near the intense heat of the crucible."

According to Höganäs, last year the Laufenburg plant supplied a considerable proportion of the several hundred tonnes of powder used worldwide for industrial Additive Manufacturing, with this quantity expected to increase significantly, as demand continues to rise, particularly in the energy, medical and aerospace markets.

Human Gherekhloo, Manager of Applied Technology at the Höganäs Laufenburg site, commented, "The individual production of high-end components for critical applications is growing rapidly. This not only requires stable production processes, but also places ever-increasing demands on the physical and chemical properties of the raw material."

The company states that the VIGA launch serves as a blueprint for further planned conversion and expansion measures in Laufenburg.

www.hoganas.com

Sourcing tantalum from non-allied nations prohibited in latest US DoD interim rule

The US Department of Defense (DoD) issued an interim rule on September 29, 2020, that will require DoD contractors to cease supplying tantalum originally sourced in various forms from 'adversarial foreign suppliers', identified as Russia, China, Iran and North Korea.

The DoD's new rule (DFARS 225.7018) restricts the department from purchasing tantalum oxides, metals, and alloys which were derived at nearly any point in the supply chain from the named countries.

The rule formally implements a national security measure, signed into law in 2019, designed to limit the US DoD's exposure to non-allied sources for tantalum. With wide uses in key defence technologies, tantalum is designated a critical mineral in the US, whose absence "would have significant consequences for the economy or national security," according to the US Department of Interior, 2018.

DFARS 225.7018 implements section 849 of the National Defense Authorization Act (NDAA) for Fiscal Year 2020. Section 849 of the NDAA added tantalum to an existing statute (10 U.S.C. §2533c) that lists critical materials the US DoD cannot source (with few exceptions) from Russia, China, Iran, or North Korea.

www.dod.defense.gov

MTC Powder Solutions expands team at its recently upgraded production facility

MTC Powder Solutions (MTC PS), Surahammar, Sweden, has added five new employees to its team based at the recently upgraded production site in Surahammar.

The new employees will be spread over the complete value chain, states the company, with positions in sales, design, project management and production.

According to MTC PS, with interest in Additive Manufacturing introducing a new design mentality across multiple industries, more existing designs are being challenged and interest in Powder Metallurgy near-net shape (NNS) Hot Isostatic Pressing (HIP) components is increasing.

"It was a natural step to increase the capacity in our design department with one permanent additional design engineer to align with our customers' increased demand for rapid design input in a variety of developments," commented Fredrik Johansson, Technical Manager at MTC PS.

"As reducing cost becomes more and more evident in most sectors, we see a clear tendency that customers are relying more on our competence as a PM, NNS & HIP manufacturer to suggest changes on existing and new applications. Changes which support increased performance and reduced project costs."

www.mtcpowdersolutions.com

mG miniGears receives best supplier award from Schaeffler

mG miniGears, the Italian-based Powder Metallurgy precision parts division of hGears Group, has received a 'best supplier' award from Schaeffler Group.

Presented during the Schaeffler Digital Supplier Day, the 'Partners For Performance' awards honour companies who have been recognised as top suppliers to the group.

miniGears was awarded best supplier in the 'Transformation' category for its continuous improvement of manufacturing processes (material flow, shop floor layout, automation, machine data connection and digitalisation), based on lean manufacturing concepts.

Representatives of Schaeffler Group were reported to have visited the miniGears plant recently to present the award in person. "We are very proud and honoured to receive such an award and to be a valuable and reliable partner in providing New Mobility system solutions," stated mG miniGears.

www.hgears.com

Blue Power and Amazemet develop compact ultrasonic atomiser

Blue Power Casting Systems GmbH, Walzbachtal, Germany, in cooperation with Amazemet Sp. z o. o., a Warsaw University of Technology spin-off company, have developed a compact ultrasonic atomisation unit for R&D purposes and small powder batch production.

Dr Fischer-Bühner, Head of R&D at Blue Power, explains that the atomiser unit enables users to produce small batches of high quality, spherical powder for the same target application as gas atomised powder at an affordable price and without complex infrastructure.

Blue Power and Amazemet's collaboration results in a new ultrasonic atomisation unit (Courtesy Blue Power Casting Systems GmbH)

The ultrasonic atomiser solution features a crucible-based induction heating system which allows the melting temperature to be precisely controlled, thereby preventing the loss of alloy ingredients such as zinc and chromium through evaporation. The melting can either take place under vacuum or in a controllable atmosphere. The powerful medium-frequency induction generator produces excellent stirring/mixing effect, improving the quality of the alloying.

"A crucible-based induction heating system has many economic benefits over plasma-assisted ultrasonic atomisation," commented Mateusz Ostrysz, co-founder of Amazemet.

For example, the loss of alloy ingredients through evaporation is prevented without the need for any sophisticated and expensive filtration systems, state the companies. The system is not restricted to just pre-alloyed wire and bar; the feedstock can be any shape. This means that users can avoid the time and effort needed to produce complex and expensive wire, no longer needing the associated infrastructure such as continuous casting machines and drawing benches.

Very small batch sizes, of around 100g or less, are reported to be both technically and financially viable, while larger production capacity of up to several kg (bronze) per hour is possible. An increased powder yield is made possible due to operating at a higher frequency (up to 80 kHz). For example, bronze particle sizes in the range of d50= 40-60 µm can be easily achieved, with further improvements on the horizon.

The ultrasonic process is said to offer the flexibility users require in terms of both inputs and outputs. The plant can reportedly handle almost any non-ferrous metal in any shape with a melting temperature less than 1300°C, with the company also developing an 1800°C version. No calibration is needed; pre-installed programs cover the basic materials and alloys. The machine can also be used for granulating and ingot casting.

www.bluepower-casting.com
www.amazemet.com

Roboworker launches RPS Compact for precision part handling

Roboworker Automation GmbH, headquartered in Weingarten, Germany, a producer and supplier of automation and inspection systems, reports that it has launched the RPS Compact, a new machine for re-palletising a wide variety of precision parts from, and onto, all tray types.

The RPS Compact can sustainably increase the productivity of all manufacturers of high-quality small parts (< 100 mm), states the company. The basic system consists of tried and tested modules for tray and parts handling, which can be flexibly combined with each other. It can be extended with various inspection functionalities or sample processing using the latest software technologies and image processing systems.

According to Roboworker, the system can be set up in a very short time and is then ready for operation and equipped for new products. Having an optimised footprint, the RPS Compact is available as a standalone version for manual loading as well as with a docking system for loading via AGV or for inline integration.

Key characteristics of the RPS Compact system include:

- Portal robot with combi grippers for flexible tray handling
- Precision robot with an integrated gripper exchange interface, as well as an interface for position detection
- Universal gripper set for all kinds of part and a gripper station for automatic gripper change
- Automatic change-over to the next order and part type
- Simple operation via a touch screen, with the latest HMI and Windows 10 based control technology
- Optional connection to ERP system

www.roboworker.com

Alloyed and Taniobis collaborate to develop advanced titanium and refractory alloy metal powders

Metal powder development company, Alloyed, London, UK, and Taniobis, based in Goslar, Germany, have announced a collaboration to identify, develop, produce, and implement innovative high-quality titanium and refractory alloy metal powders for use in advanced manufacturing applications including Additive Manufacturing.

The partnership is said to enable a full end-to-end solution for the material development process, including material analysis and qualification, material production, component design and performance, and also into pilot production. Alloyed and Taniobis will work on a broad spectrum of projects, some with third parties, for a range of applications across the medical, aerospace, and e-mobility industries.

"At Alloyed we are very happy to be working with the global team at Taniobis to progress innovations with new titanium and refractory alloys for AM," commented Michael Holmes, Managing Director of Alloyed.

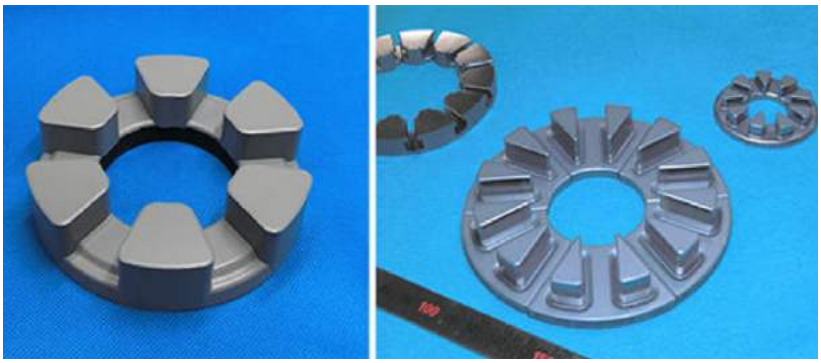
"The Alloys By Design (ABD) platform, coupled with Taniobis' long-standing and world-leading expertise with tantalum and niobium materials has the potential to open up some new and very exciting application areas for advanced manufacturing applications. This capability together with the Betatype technology stack for adding performance to critical components makes this alliance even more powerful. We are excited to bring these developments to fruition in due course," Holmes continued.

Katarzyna Kosowski, who heads Corporate Business Development & Communication at Taniobis stated, "There is great synergy between Taniobis and Alloyed that I believe will serve our clients in limitless ways when it comes to providing end-to-end solutions for new and greatly improved applications with metal AM technologies."

Kosowski added, "By collaborating with the experts at Alloyed and their exceptional ABD platform, we are extending our reach and capabilities into new and innovative areas for advanced manufacturing and particularly for Additive Manufacturing. The opportunities that AM affords has been well documented, but unlocking new materials for AM remains a constant goal. Together with Alloyed, we at Taniobis hold one of the keys."

www.alloyed.com
www.taniobis.com

Sumitomo Electric develops powder magnetic core for thin and high-performance motors



Left: Insulation-coated powder magnetic core for axial gap motors (mass-produced product). Right: Powder magnetic cores for axial gap motors (prototype) (Courtesy Sumitomo Electric Industries, Ltd)

Sumitomo Electric Industries, Ltd., headquartered in Osaka, Japan, reports that it has developed a powder magnetic core for axial gap motors, said to be advantageous for creating thin and high-performance motors in terms of output and efficiency. The company started mass production and delivery of the product in August 2020.

According to Sumitomo Electric, with the recent growth in demand for light and high-performance motors, axial gap motors are attracting more attention due to their light weight, low thickness, and high power density, achieved by adapting a different structure from conventional motors (radial gap motors).

In order to produce axial gap motors, high-quality magnetic cores that suit their three-dimensional magnetic circuits are required. Using its Powder Metallurgy technology, Sumitomo Electric has developed a powder magnetic core that helps to realise high-performance axial gap motors.

In addition, the company has developed a new insulation coating technology to ensure the dielectric strength between the powder magnetic core and the copper winding, and has started the mass production and delivery of the insulation-coated powder magnetic core as an ideal component for axial gap motors.

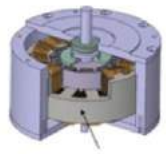
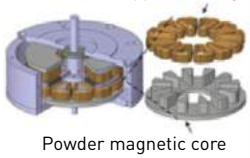
Features of the powder magnetic core for axial gap motors

The powder magnetic core is formed by die-pressing soft-magnetic iron powder into a three-dimensional shape. Compared to the magnetic cores made of electrical steel sheets used in conventional radial gap motors, the PM route offers great flexibility in terms of shape design and superior high-frequency characteristics, and has been put into practical use in various fields, such as automobile applications.

When using a powder magnetic core for a motor, an additional component must often be provided to ensure the dielectric strength between the magnetic core and the copper winding. However, the company states that its unique insulation coating technology has made it possible to wind copper wire directly around the powder magnetic core, and thereby reduce costs for additional components and assembly. This feature has also made it possible to expand the winding space, which contributes to the development of more compact and efficient motors.

In addition, Sumitomo Electric provides assistance for three-dimensional electromagnetic field analysis of axial gap motors based on motor specifications provided by customers, so that they can realise the advantages of the powder magnetic core for axial gap motors.

www.global-sei.com

	Radial gap motor (conventional)	Axial gap motor
Structure (Schematic diagram)	 Electrical steel sheet	 Copper winding Powder magnetic core
Short axial length (mm)	83.0	35.0 (-58%)
Weight (kg)	3.2	1.6 (-50%)
Torque (N · m)	0.65	0.65 (-)
Maximum efficiency (%)	90.6	90.9 (+0.3%)

The table shows electromagnetic field analysis for an axial gap motor (Courtesy Sumitomo Electric Industries, Ltd)

Submitting news...

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Contact Paul Whittaker:
paul@inovar-communications.com

AAM Powder Metallurgy plant receives quality award in 22nd Ford World Excellence Awards

American Axle & Manufacturing, Inc., (AAM), Detroit, Michigan, USA, reports that it was announced as a silver winner at the 22nd Annual Ford World Excellence Awards, which took place virtually this year.

AAM was recognised with a silver award for quality at its manufacturing facility in Valencia, Spain, which specialises in the production of components including Powder Metallurgy connecting rods.

"AAM's number one objective is to manufacture the highest quality and most innovative driveline and metal forming technologies," stated David C Dauch, AAM chairman and CEO. "This award is the ultimate recognition of that work and we thank Ford for their support of AAM."

Hau Thai-Tang, Ford's Chief Product Platform and Operations Officer, commented, "Ford's annual World Excellence Awards recognise our top-performing suppliers for their contributions to our success. Congratulations to AAM for being a recipient of this coveted award. Thank you for all that you do in support of Ford Motor Company."

American Axle & Manufacturing's facility located in Valencia, Spain, received a silver award for quality from Ford (Courtesy AAM)

Honourees were recognised for achieving the highest levels of global excellence in categories that included:

- Gold and silver for supplier manufacturing sites demonstrating superior quality, delivery and cost performance throughout the year
- Primary brand pillar awards in winning portfolio, propulsion choices, autonomous technology and connected services categories
- Fitness awards for suppliers that most exemplify the framework's principles, with an emphasis on quality, value and innovation
- Special recognition for suppliers that deliver results exceeding expectations
- Diverse supplier of the year and supplier diversity development corporation of the year for suppliers that excel in integrating diversity into their organisation and business process

www.aam.com

ECM Technologies launches new oil quenching furnace system

ECM Technologies, an industrial furnace manufacturer headquartered in Grenoble, France, has released its new oil quenching furnace system, ECO, which the company states will replace its current sealed quench (SQ) or integral quench (IQ) style furnaces.

The new ECO furnace system is said to offer cleaner, safer and better performance overall in comparison to traditional SQ or IQ furnaces on the market.

According to ECM Technologies, when developing this new furnace, the company took into consideration all the key characteristics of SQ or IQ furnaces and eliminated their drawbacks. All development was said to be based on four pillars: environmental impact, efficiency, metallurgical quality and existing inline integration.

The ECO furnace is an electrically heated system, enabling a CO_2 emissions reduction of more than 80%. It also allows for higher temperatures, thereby enabling increased productivity through greater throughput, states the company.

In addition, a safer and more ergonomic environment is provided without open flames and smoke, eliminating the risk of fire hazards.

Furthermore, the ECO furnace can reportedly be integrated with existing SQ or IQ lines using existing pits, conveyors and peripheral equipment (tempers, washers, etc).

ECM Technologies has released ECO, its new oil quenching furnace system (Courtesy ECM Technologies)

ECM Technologies explains that the ECO line allows captive and commercial heat treaters to extend the life and expand the capabilities of its existing SQ or IQ furnace lines. Part quality is also said to reach higher levels with efficient and safe heat treatment processes.

www.ecm-furnaces.com

US government awards 6K $1 million for defence scrap recycling

6K, a developer of microwave plasma technology for the production of advanced materials headquartered in North Andover, Massachusetts, USA, and its AM-focused business division, 6K Additive, has been awarded a Phase ll SBIR programme from the US government's Defense Logistics Agency (DLA), following the strong success of its Phase I.

The Phase II programme supports the development and commercialisation of a domestic and commercially scalable supply chain for strategic high-performance metal powders from scrap sources. Using 6K's proprietary UniMelt® microwave plasma platform, the programme will demonstrate 6K's capability to source, process and reclaim nickel superalloy scrap components, shop scrap, and used powders for conversion into aerospace-grade powders which will be used to additively manufacture real-world, discrete parts which will demonstrate functionality in test beds or systems.

Dr Aaron Bent, CEO of 6K, stated, "As a company we are certainly pleased with the award, but more importantly, we're proud as an organisation to help our country create and control a domestic supply for alloys such as nickel used for emerging production methods like Additive Manufacturing. The recent COVID-19 pandemic highlights the importance of controlling supply chain and the renewed need for domestic production to avoid interruption of critical supplies."

6K's UniMelt plasma production system is capable of converting high-value metal scrap in numerous forms into high-performance metal powders for AM, Metal Injection Moulding (MIM) and other Powder Metallurgy production techniques.

In doing so, the company can reportedly provide access to a large domestic supply of strategically important metals and alloys such as nickel and titanium from machine shops, boneyards, and other sources of used materials which are critical to defence manufacturing.

The 6K process cleans, prepares, and spheroidises scrap alloys into high-quality powders with performance said to be superior to that of materials manufactured using atomisation technologies. This is expected to provide the US military with a secure, traceable and domestic supply of critical materials, while eliminating unexpected performance anomalies due to questionable sourcing from foreign supply.

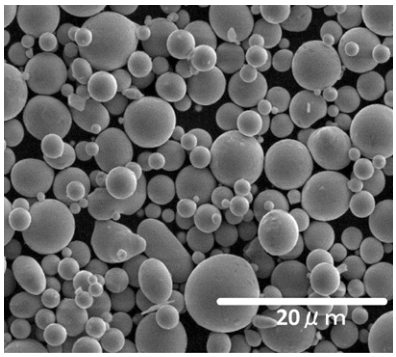
6K has recently commissioned a new, approx. 3700 m^2 state-of-the-art metal powder production facility and will begin shipping traditional powder products in the fall of 2020.

www.6kinc.com

Epson Atmix adds new water atomisation production line

Epson Atmix Corporation, Aomori, Japan, an Epson Group company, has begun operations on a new production line at its Kita-Inter Plant, Hachinohe, Japan. Built with an investment of approximately JP¥1.5 billion, the new line uses a water atomisation process to produce superfine alloy powders.

The new line will enable Epson Atmix, which also produces superfine alloy powders at its Head Office Plant, to increase its total production capacity to around 15,000 tons per year, about 1.5 times its current production capacity, by 2025.



Epson Atmix's new line uses a water atomisation process to produce superfine alloy powders (Courtesy Epson Atmix Corporation)

The company's water atomised superfine alloy powders are classified into two main types, depending on what they are made from and how they will be used: powders for magnetic applications and powders for Metal Injection Moulding (MIM).

The company explained that it has added its own technology to a water atomisation process in which high-pressure jets of water are impinged on a stream of molten metal from a high-frequency induction furnace to cause the metal to burst into a mist that is then rapidly cooled. This process enables the production of micron-order granules to supply superfine alloy powders that are consistent and have uniform composition and characteristics.

Atomised powders are used in MIM parts that have complex shapes and that require high dimensional accuracy and strength, such as parts for medical equipment, automobile engine applications, electronic equipment, and office-automation equipment. Demand is also expected to grow as metal Additive Manufacturing technologies become increasingly widely used throughout industry.

Epson Atmix's lineup of MIM-grade powders includes stainless steels and low-alloy steels. The grain size can be adjusted according to the application to increase sintered part density and strength.

Magnetic-grade powders serve as the raw materials for electronic components such as inductors, choke coils, and reactors required to control the voltage of high-performance mobile devices such as smartphones and laptop computers. The market for these powders is expected to expand further in the future, owing to an increase in the use of electrical components in automobiles and an increase in the number of inductors installed in hybrid and EV vehicles.

Epson Atmix's magnetic-grade powders control energy loss using the company's technology for producing micro-granules. These powders also contribute significantly to reducing the power consumption and size of electrically controlled components, and to the support of high frequencies and large currents.

www.atmix.co.jp

Mimete releases new iron-base powders F51 and F53 for demanding applications

Mimete S.r.l., Biassono, Monza, Italy, has released two new iron-base powders, Duplex MARS F51 and Super-duplex F53. The company, a division of Italy's Fomas Group, established a new powder production plant in May 2019 utilising a customised vacuum inert gas atomisation (VIGA) system. While the company initially focused on the production of standard powder grades, with some experimentation on customised alloys, research was also undertaken on which alloys could guarantee the easiest entrance into the market for metal Additive Manufacturing powders used in highly demanding industries such as oil & gas, power generation and aerospace. This led to the production of a number of special alloys, such as F51, together with high-carbon steels and Ni-base alloys. These materials were produced in a wide range of grades, suitable for different AM processes (BJT, PBF and DED) along with coating and HIP applications.

Duplex steel F51 is a widely used material, where the relatively high content of Cr, Mo and Ni generates improved mechanical properties when compared to austenitic stainless steel. It also offers good pitting corrosion resistance and stress cracking resistance. F53 is a highly alloyed duplex steel, referred to as a super-duplex, distinguished by its much higher corrosion resistance, making it suited to highly critical atmospheres and environments.

"Mimete's team effort and dedication are bringing our duplex and super duplex stainless steel powder to the market. We are proud to provide our customers with high-quality powders that will be used in applications where maximum performance is required," stated Andrea Tarabiono, Mimete's Manufacturing Director.

Duplex and super-duplex mechanical properties are well known to the oil & gas and maritime industries. These industries are looking at AM with deep interest, as it could lead to lower operating costs by streamlining production processes and developing a lean supply chain. By offering materials that are known to these industry sectors, it is hoped that Mimete can help to increase the adoption of AM.

www.mimete.com

SMS group holds groundbreaking ceremony for its new campus in Germany

Left to right: Torsten Heising (CFO, SMS group GmbH), Holger P Hartmann (architect and general planner), Hans Wilhelm Reiners (Mayor of Mönchengladbach), Peter Peskes and Elke Paul (works council chairpersons), Heinrich Weiss (Chairman of the Shareholders' Committee of SMS Holding GmbH), Marco Kubiak (project manager), Burkhard Dahmen (CEO, SMS group GmbH) (Courtesy SMS group GmbH)

SMS group GmbH, headquartered in Düsseldorf, Germany, reports that construction has begun on its new campus in Mönchengladbach, Germany, with the company holding a groundbreaking ceremony.

Mönchengladbach will be home to a new technology, service and digitalisation centre built on the SMS group's premises and provide 1,500 modern workplaces. From 2023, the competences of five locations in the region will be brought together at this central location in the Rhineland. The company currently has over 1,200 staff employed in Mönchengladbach.

SMS group explains that the new campus will cover a gross surface area of approximately 44,000 m^2 and consist of five-module buildings. The core of the complex will be a covered atrium serving as a meeting and communication area and a membrane-type roof with a diameter of 82 m will connect all buildings to create a unique campus.

In addition, an adjoining staff car park will offer sufficient parking space and will be equipped with charging stations for electric cars and bicycles. Given the future investments in the infrastructure of the immediate neighbourhood by the city of Mönchengladbach, the whole district will be upgraded and the new campus will become well connected with the local public transport system, states the company.

During the ceremony, Hans Wilhelm Reiners, Mayor of Mönchengladbach; Heinrich Weiss, chairman of the Shareholders' Committee of SMS Holding GmbH; Burkhard Dahmen, CEO of SMS group GmbH; Torsten Heising, Member of the Managing Board of SMS group GmbH; and Works Council Chairpersons Elke Paul (Düsseldorf) and Peter Peskes (Mönchengladbach) broke ground together with project manager Marco Kubiak, and architect and general planner Holger P Hartmann."

"We see huge growth potential from the interaction of technical service and digital solutions," stated Burkhard Dahmen. "Our Campus will enable us to connect these technologies closely with our product units, bringing together specialists from all over the world to form interdisciplinary teams via virtual infrastructures."

Heinrich Weiss, commented, "With this new complex we are providing a significantly enhanced working environment, making us an extremely attractive employer for future talent."

Torsten Heising reported, "Our recent experience with various forms of mobile working options has shown us that we can actually get our work done wherever we are."

He continued, "For creative processes, though, we still need a shared environment that makes us feel inspired. The open architecture of the new campus promotes our corporate culture and enables us as an employer to take into special consideration what our highly skilled workforce expects from a modern workplace."

In total around 70,000 m^3 of soil will be removed, with shell construction work for the five-module buildings due to start in the spring of 2021. The shell construction is scheduled to be completed by the summer of 2022, and the campus is planned to be ready for occupancy in mid/end-2023.

www.sms-group.com

A rendering of the new campus site in Mönchengladbach (Courtesy SMS group GmbH)

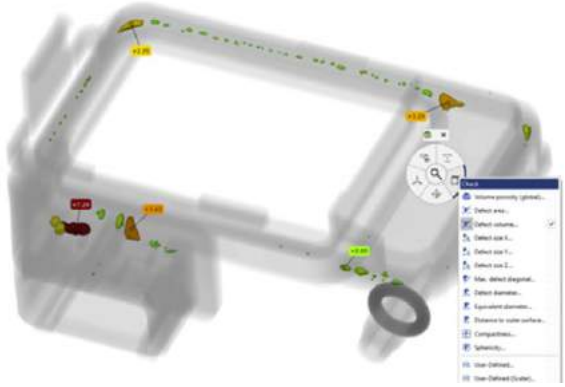
GOM releases new software for 3D CT data analysis

GOM GmbH, Braunschweig, Germany, a ZEISS Group company, has released its new software solution GOM Volume Inspect, which provides volume visualisation and inspection features for analysing volume data collected from any available computed tomography system (CT).

GOM Volume Inspect is part of the company's new software platform, GOM Inspect Suite, which embraces and facilitates the complete workflow from scanning to reporting for maximum ease of use. The new software is said to simplify volume analysis tasks significantly while offering deep insight on a part's geometries, voids or internal structures, as well as multi-part assembly situations.

GOM Volume Inspect offers full 3D data analysis to evaluate a part's quality and optimise the manufacturing process. As the software features an on-demand data management concept, it is said to be able to deliver high performance even in the case of large volume data packages and speed up analysis processes.

GOM Volume Inspect includes the following features:



A screenshot of shrinkage cavities as shown by GOM Volume Inspect (Courtesy GOM GmbH)

- **Volume renderer and intuitive generation of sectional views**
  A volume rendering function visualises the whole part, including internal structures. The user can cut the object at any point and view it layer by layer in order to see the smallest details and gain in-depth information about the quality of the part
- **Wide range of analysis criteria and result presentation**
  The software automatically detects any volume defect in a part, such as shrinkage cavities, and accurately evaluates the quality by checking defect dimensions including volume, diameter and distance from outer casing.
  It is also possible to evaluate the dimensions of CT volume data – be it full-field evaluations, GD&T or inspections of geometric dimensions on the outside of the part, as well as on internal structures. The software walks the user through the complete analysis process and delivers the measured results in a transparent report with a single click. The report may include snapshots, images, tables, charts, text and graphics.
- **Trend analysis and part-to-part comparison**
  GOM Volume Inspect also includes a reportedly unique function that allows the user to load the volume data of several parts into one project, and execute a trend analysis on this data. This automated comparison is a true advantage for quality assurance managers who measure parts on a regular basis in order to derive a quality trend from the measurement data. The function also works on part-to-part comparisons, e.g. when comparing identical parts delivered from different suppliers.
  The software offers a range of free volume inspection functionalities, including 3D volume rendering, display of 2D volume slices, as well as defect detection and visualisation.

The full version of GOM Volume Inspect, providing the full extent of the above-described volume data analysis capabilities, is available as a free thirty-day trial.

www.gom.com

Metal powder atomisation specialist Sheikhali M Sheikhaliev has died

Prof Dr Sheikhali M Sheikhaliev, a material scientist and inventor of numerous atomising technologies, passed away suddenly in Novouralsk, near Ekaterinburg, Russia, in June 2020. Having worked closely with Dr Shekhaliev at UK-based Atomising Systems Ltd (ASL) over a number of years, Dr John Dunkley recounts his career and highlights some of his work in the development of atomisation technologies.

Dr Sheikhali M Sheikhaliev was born in 1946 in Dagestan, in the Caucasus, and in 1977 graduated from the Ural Polytechnic Institute. After postgraduate study, he worked at Moscow Engineering Physics Institute No 2 (MIFI-2), located in Novouralsk, 1,400 km from Moscow. Dr Sheikhaliev both lectured and conducted research in materials science, largely connected with the nuclear industry. He authored more than twenty patents and 120 publications on materials science and his work allowed the creation of new materials for nuclear reactors. He trained more than 150 specialists for the nuclear industry. In 1990, working from the Institute, he founded a company to develop novel powder atomisation techniques called Ural Netramm (UN). It was around this time that I first met him in Moscow, having read his articles in *Poroshkovoya Metallurgiya* considering the possibilities of applying highly unconventional techniques of atomisation to metals.

Atomising Systems Ltd took his concept for ultrasonic solder atomisation and applied western specialist equipment to develop a practical system for atomising electronic grade solder to extremely spherical and narrowly sized powder, and succeeded in selling several systems to Japan, China and USA, before the electronics industry moved to finer powders, which required higher frequencies which in turn implied lower throughputs than were viable.

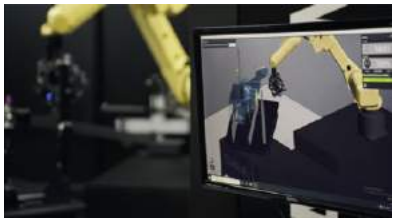
Another area of cooperation between Dr Sheikhaliev and ASL was in modelling centrifugal atomisation. Here, he developed a computer programme that predicted the trajectory and thermal history of flying metal droplets, and this has proved useful to ASL in designing production plants for solder powders, lead shot, zinc for batteries, bronze powder, steel powders, and even silicon.

He also propounded and demonstrated the concept of using pressure-swirl nozzles for metals. These are the most common form of atomising nozzle for cold liquids, e.g. for perfume, but the obvious problems for metals are pressurising the melt and nozzle material durability. ASL succeeded in building a highly successful plant in 1995, using this technique to produce a fountain of molten lead which made excellent, narrowly distributed lead shot around 0.5–1.0 mm.

Dr Sheikhaliev also worked together with the German Institute IWT in Bremen, where Dr Uhlenwinkel worked with one of his students to demonstrate his concept of pressure gas atomisation, which combined a first stage pressure swirl jet, to produce a conical sheet of molten metal, with a second stage gas atomisation of this sheet.

Creaform introduces new suite of automated dimensional quality control solutions

Creaform, a 3D measurement solutions provider based in Lévis, Québec, Canada, has announced the latest release in its R-Series™ lineup, including its new MetraSCAN-R BLACK|Elite™ as well as the addition of four different models in its CUBE-R 3D scanning measuring machine. Creaform also launched its VXscan-R™ digital twin environment software module, which completes the company's turnkey automated quality control solution suite.



Creaform's 3D measurement solutions offer fast and accurate scanning for automated quality control (Courtesy Creaform)

Designed for automated quality control applications, the R-Series 3D scanning solutions are said to enable manufacturing companies to increase productivity by measuring more dimensions on more parts, without compromising on accuracy. The MetraSCAN 3D-R is a robot-mounted optical CMM scanner that can be seamlessly integrated into automated quality control processes for at-line inspection in mass production.

The CUBE-R is said to leverage the power of the MetraSCAN 3D-R in a high-productivity industrial measuring cell designed to be integrated into factories for at-line inspections. Compared to traditional CMMs, the CUBE-R is reportedly faster, providing improved productivity and efficiency.

"Manufacturers need to achieve fast, accurate and repeatable output – now more than ever before. With Creaform's automated quality control solutions, manufacturers can increase their productivity," stated Jérôme-Alexandre Lavoie, Product Manager at Creaform.

"By detecting and addressing quality issues faster based on statistical analyses, corrective measures can be more proactively implemented to mitigate total quality costs (TQC) and unprofitable recalls," concluded Lavoie.

www.creaform3d.com

Buehler introduces Wilson RH2150 Rockwell Hardness Tester

Buehler, Lake Bluff, Illinois, USA, has introduced its newest Rockwell Hardness Tester, the Wilson RH2150, an updated Rockwell tester said to offer easy programmability, advanced calculations and verification reminders to ensure compliance.

The Wilson Rockwell RH2150 was showcased at the International Materials Applications & Technologies (IMAT) Virtual Show, run from October 26–28, 2020. The launch of the new Wilson RH2150 coincided with the centennial anniversary of the Wilson brand of hardness testers, test blocks and software.

The RH2150 is available in two different sizes, with a vertical capacity of 254 mm or 356 mm. It is fully protected from outside influences with sheet metal casing and a load cell protection. Buehler states that it has improved the Rockwell with a clamping device that is attached to the actuator, extended scales, crash protection and a new user interface with intuitive icon-based controls. The new model also offers programmability and workflow automation and 'one button' testing.

According to Matthias Pascher, Buehler's Hardness Product Manager, "The RH2150 was tested for weeks and months in harsh workshop environments and the consistency of test results and intuitive testing controls is clearly standing out and is the key requirement for this type of hardness testing machine."

"We designed unique features, such as the clamping device, directly mounted on the actuator, intelligent footswitch controls, or the DiaMet™ software package for advanced testing and reporting solutions, including network connectability which is more and more a need to ensure complete test result traceability," he explained.

The machine performs hardness testing according to the current

Buehler's new Wilson RH2150 Rockwell Hardness Tester (Courtesy Buehler)

Rockwell standards and Brinell depth testing scales, all within the load range from 1 to 187.5 kgf. Users in the manufacturing and heat treatment industries rely on Rockwell standards, making this an important criteria for production testing.

As well as being showcased during the IMAT Virtual Show, the Wilson RH2150 was demonstrated at Buehler's Wilson Hardness Days 2020, featuring in a number of hardness testing webinars.

www.buehler.com

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Ametek sees increasing demand for metal powders used in ventilator parts

Ametek Specialty Metal Products (SMP), headquartered in Collegeville, Pennsylvania, USA, reports that it is seeing increasing demand for metal filter powders for ventilators. The metal filter powders are produced through the company's business division, Ametek SMP Eighty Four, based in Eighty Four, Pennsylvania, USA. The company reported earlier this year that it was meeting demand for critical ventilator components, which had increased due to the coronavirus (COVID-19) pandemic. Ametek SMP Eighty-Four reports that it is still seeing increasing demand for the highly-customised metal filter powder used in medical applications. These specialised materials are used in a variety of medical products, such as porous flow restrictors in ventilators to control oxygen flow and prevent clogs in the system.

As the starting material, these powders need to be extremely consistent and precise in size to achieve a tailored and controlled range of end filtering properties. From coarse, gravel-like grains to micron-sized powders less than a tenth of the diameter of a human hair, different sized particles are crucial for different applications.

Ametek SMP Eighty-Four produces filter powders using a highly refined water atomisation technology to ensure the production of high-quality powder that meets the exact requirements of medical filter manufacturers and OEMs. This process is capable of producing bespoke powders in a wide variety of metals, from stainless steels to nickel and cobalt alloys.

The company's engineers have tailored this process to form the highly irregular shapes of powder grains that are critical for medical filter production. The filtration powders produced are then pressed and shaped by the filter producers to offer precision assistance with flow control in ventilators.

Brad Richards, Product Manager for Powders at the Ametek SMP facility in Eighty Four, stated, "We have a very comprehensive portfolio in terms of supplying any speciality or customised alloy powders that a medical or industrial producer might need for their filter grade powders. The primary materials that we make for medical powders are alloys of 316L and 17-4PH stainless steel, as well as various nickel-based alloys."

He continued, "We also have a very long legacy of producing filter powders, going back to the 1970s when we were operating one of the very first water atomised powder production plants. Our customers appreciate the quality of our filter grade products, the longevity of our operations, and, of course, our technical know-how."

The company works with many filter customers who require specific, tailored alloys for their applications, or extremely precise particle size distribution. More than twenty-five different sizes of filter powders are currently produced at Eighty Four.

www.ametekmetals.com

Ametek SMP Eighty-Four's water atomised metal filter powders, which are used in ventilator components (Courtesy Ametek Specialty Metal Products)

Kittyhawk partners with Synertech PM to provide build plates for AM

Hot Isostatic Pressing (HIP) company, Kittyhawk, headquartered in Garden Grove, California, USA, reports that it has entered a partnership with Synertech PM Inc, a Powder Metallurgy parts manufacturer also based in Garden Grove, to offer a range of build plates for Additive Manufacturing machines.

Build plates are an essential element in providing stability and quality in Additive Manufacturing processes. However, Kittyhawk explains that some of them are not readily available and can be costly. The company states that it can also be difficult to acquire thicker plates when a process requires them, for example. Additionally, the inherent anisotropy of rolled plates can impact the dimensional precision of the AM process.

Jointly, the companies will provide uniform and homogeneous PM HIPed rectangular blanks, yielding the necessary amount of build plates to the optimal thickness for AM machines. Build plates made by Powder Metallurgy and HIPed are 100% dense with fine-grain microstructure, states Kittyhawk, resulting in minimised warping during Additive Manufacturing processes and producing fewer restrictions on the positioning of the built parts on their surface.

Kittyhawk states that its HIP equipment and canning technology enables the production of blanks with the cross-sections from 25 x 25 cm up to 76 x 127 cm. Lead time for the blanks are four-five weeks, with readily available materials including Ti 6-4 Grade 5, Ti 6-4 Grade 23, Ti Grade 2, IN 718 and IN 625.

www.kittyhawkinc.com
www.synertechpm.com

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Global Tungsten & Powders focuses on the production of tungsten metal powders, tungsten carbide powders, and ready-to-press powders for the hard metal industry, oil & gas, thermal spray, additive manufacturing, and many more industries. Our laboratories are equipped with the latest testing technologies analyzing material down to the atomic level.

GTP will recycle any tungsten containing scrap you may have from your processes. Benefit from our long standing expertise especially in utilizing the zinc process for recycling of tungsten carbide in industrial scale. Let us discuss how we can help.

During the 2020 COVID-19 pandemic, GTP kept all production locations operative 24/7. Rely on our plants in the US, Finland, and in the Czech Republic, to provide you with an uninterrupted supply chain independent from China.

www.globaltungsten.com

Abbott Furnace installs endothermic gas generator at Powder Metallurgy parts maker Sintergy

Abbott Furnace Company, St. Marys, Pennsylvania, USA, reports that it has designed, manufactured and installed a new 6,000 SCFH Endothermic Gas Generator at Powder Metallurgy parts maker Sintergy, Inc., based in Reynoldsville, Pennsylvania, USA.

The design of the Abbott SP-6000 generator is a modular concept with each module producing up to 6000 SCFH of endothermic gas.

Abbott states that the generator offers an innovative retort design that allows a single retort to produce endo gas at this rate without sacrificing gas quality, while maintaining 6:1 turndown ratio. Sintergy is said to be pleased with the level of control that the new system gives, reporting only seeing a ±1°F dewpoint variation from setpoint.

Abbott added that the new generator houses a number of improvements, including state-of-the-art controls with Allen Bradley PLC, data logging, dewpoint and methane sensors, as well as an updated gas safety system.

www.abbottfurnaceco.com
www.sintergy.net/index.php

Abbott Furnace has commissioned and installed an endothermic gas generator for PM parts maker Sintergy, Inc. (Courtesy Abbott Furnace Company)

US government announces investment in British rare earth specialist

The US government has invested $25 million in TechMet, a mining group based in London, UK, which specialises in rare earth production, according to *The Telegraph*. The investment is made with the aim of creating rare earth supply outside China, which currently controls the global flow of materials such as cobalt and lithium.

The investment in TechMet will reportedly help fund the development of a mine in Brazil set to produce nickel and cobalt, essential materials for the production of electric vehicles, batteries and cellphones. The announcement comes after US President Donald Trump signed an executive order which declared a national emergency in the mining industry, aimed at boosting domestic US production of rare earth materials.

TechMet's nickel and cobalt mine in Brazil is thought to contain up to 72 million tons of nickel and cobalt (Courtesy TechMet)

The order states that the country's "undue reliance on critical minerals, in processed or unprocessed form, from foreign adversaries constitutes an unusual and extraordinary threat, which has its source in substantial part outside the United States, to the national security, foreign policy, and economy of the United States."

China produces around two-thirds of the world's lithium-ion batteries and has taken steps to secure critical metals for them in Africa and Latin America. With the new order, the US's Pentagon has promised to finance the domestic mining of essential materials while investing in projects abroad through the deployment of the $60 billion United States International Development Finance Corporation.

TechMet's Brazilian mine is the first metals and mining investment made under the order. Mining veteran and company founder Brian Menell, a former manager of the South African conglomerate Anglovaal and De Beers, stated, "A country's national and industrial competitiveness will depend on preferential access to these raw materials."

TechMet has a tin and tungsten mine in Rwanda, a rare earth mine in Burundi, and a lithium-ion battery project in Canada. The company also produces vanadium, a key metal used in the manufacture of nuclear reactors and military aircraft. It has stated that its prospective mine in Brazil contains up to 72 million tons of nickel and cobalt.

Adam Boehler, president of the US International Development Finance Corporation, commented on the investment, "This important funding will support economic growth in one of the least developed areas of Brazil. Investing in critical materials for advanced technologies supports development and drives US foreign policy."

www.techmet.ie

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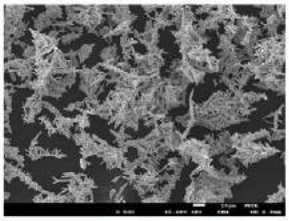
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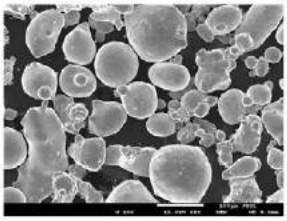
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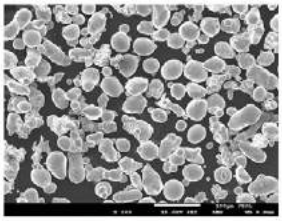
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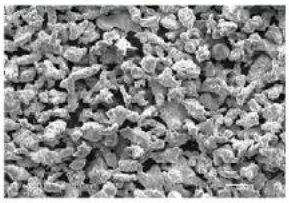
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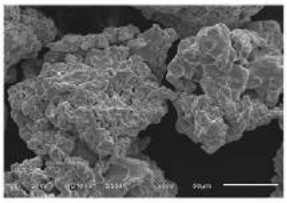
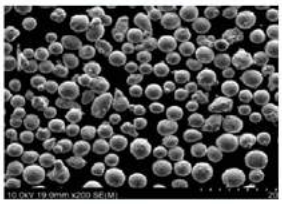

Diffusion Powder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PMCC&AC EXPO 2020 reports success and announces dates for 2021 show

The Shenzhen International Powder Metallurgy, Cemented Carbide & Advanced Ceramics Exhibition (PMCC&AC EXPO) 2020 was held from September 13–15, at The Shenzhen Convention and Exhibition Center in Shenzhen, China.

PMCC&AC EXPO 2020 was held in Shenzhen, China, from September 13–15 (Courtesy Wise Exhibition (Guangdong) Co.,Ltd.)

According to the event organisers, which include Wise Exhibition (Guangdong) Co.,Ltd., Guangzhou Machine Tool & Tool Industry Industry, and Donguan Numerical Control Cutting Association, the PMCC&AC EXPO 2020 covered an area of 15,000 m^2 and attracted 19,310 visitors from a number of different cities. Thirty-two professional purchasing groups also joined the event, including Foxconn and Huawei.

Due to the coronavirus (COVID-19) pandemic, and the resulting restrictions placed on travel and the changes to working patterns, more enterprises were said to be focusing on the domestic market. Over 200 companies participated in the exhibition, where they exhibited raw and auxiliary materials, products and equipment relevant to Powder Metallurgy and Advanced Ceramics.

Running alongside the exhibition was the 2020 Shenzhen International Powder Metallurgy Technology Development Forum, focussed on the fields of Additive Manufacturing, Application of Powder Metallurgy, Powder Injection Moulding, etc. During the forum, presentations were given by experts including Dr Q, Chief Lecturer, You neeD Technology Office; Dr Yu Peng, Southern University of Science and Technology; and Prof Li Xiaofeng, North University of China. The Second International Symposium on Amorphous Alloy Powder Technology and Application and The 10th China Small Motor & Magnetic Materials Industry Development Summit were also held alongside PMCC&AC Expo 2020.

The 2021 Shenzhen International Powder Metallurgy, Cemented Carbide & Advanced Ceramics exhibition will be held from July 1–3, 2021.

www.pmccexpo.com

Seco/Warwick and Retech introduce remote factory acceptance testing

Seco/Warwick, headquartered in Swiebodzin, Poland, and its wholly-owned subsidiary Retech Systems LLC, Buffalo, New York, USA, have implemented a comprehensive remote Factory Acceptance Test (FAT) programme to combat the difficulties posed to supplier-customer compliance verification by the coronavirus (COVID-19) pandemic.

The company states that because travel is severely restricted by COVID-19, and many engineers are currently working from home, new methods of operation must be adopted in order to carry out acceptance testing of furnaces, in which compliance is verified by testing the existing procedures and system performance. Seco/Warwick and Retech's remote FAT programme has so far been used to test furnaces for vacuum metallurgy using Vacuum Induction Melting (VIM) technology. In accordance with the Seco/Warwick Group standard, this type of equipment is normally verified in the presence of the customer in the field by performing cold and hot tests.

The first four remote tests were carried out for two Chinese customers, a customer in Mexico and a customer in South Korea. No customer engineers were required to be involved. Instead, recordings from individual cameras, sensors and viewfinders were downloaded to secured servers and made available to customers. The tests were successful, with the adopted procedures having guaranteed the reliability and completeness of the data provided. Now, the group believes these methods can be used for other customers.

"We are ready to carry out comprehensive tests of our furnaces prior to shipment. The technical infrastructure at hand enables the performance of hot tests covering most metals used in industry," explained Jacek Trzpil, Deputy Director of Operations Vacuum Melting at Seco/Warwick. "The exception is titanium, which is a metal that reacts strongly with water and has special safety procedures, including the use of a technological bunker," he added. "We verify in practice all the operating parameters of the furnace and the associated peripheral devices, such as loading systems or closed cooling circuits, in full production cycles."

Robert Szadkowski, VP Aftermarket of Seco/Warwick Group, stated, "Remote acceptance testing is a highly requested service today. I could say that the financial rationale for such action has always existed, while the epidemiological threat has been the catalyst for change. It is a win-win action. For the first time, we did not send a team of engineers and technicians from the USA to Poland for testing. This is a huge time savings for specialists who could stay in their locations and successfully analyse test runs from remote offices or home."

www.secowarwick.com
www.retechsystemsllc.com

Euro PM2020 Virtual Congress brings PM community together online

The European Powder Metallurgy Association (EPMA) organised its Euro PM2020 Virtual Congress from October 5–7, 2020. The Virtual Congress, the first online edition of the EPMA's annual Powder Metallurgy Congress, included over 160 oral presentations, with interactive Q&A discussions with the authors following each technical session.

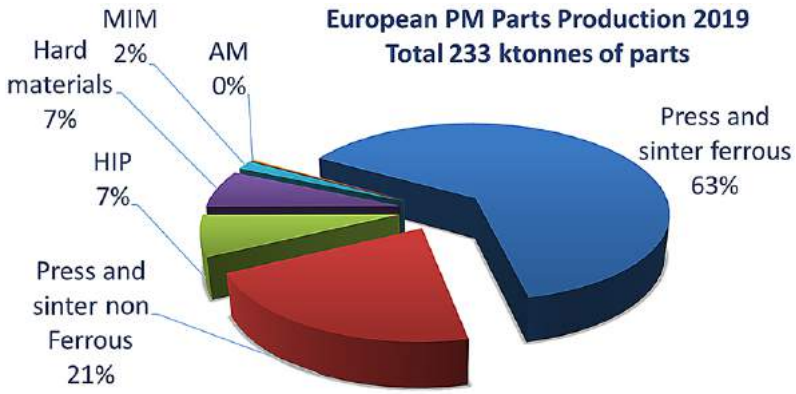
The technical programme represented all areas of Powder Metallurgy, including Additive Manufacturing, functional materials, hard materials and diamond tools, Hot Isostatic Pressing, Metal Injection Moulding, new materials, processes and applications and conventional press and sinter PM.

"Moving to a digital platform was a big challenge, but I am delighted with the event we were able to deliver. We had such a strong technical programme this year that it would have been truly unfair to the speakers not to have the opportunity to present their work," stated Lionel Aboussouan, EPMA Executive Director.

Mr Ralf Carlström, EPMA's president, opened the Plenary Presentations with an 'Overview of the status and trends in the European PM industry'. This was followed by Jean-Marie Reveille of automotive benchmarking company A2MAC1 presenting 'Current and new opportunities for PM components in New Mobility'.

"Our members are always enthusiastic about the latest research in PM, and I think we found a great method of delivering it to them," concluded Aboussouan.

www.epma.com



The opening session included an overview of the PM industry. Shown here is a breakdown of European PM part production in 2019 (Courtesy EPMA)

Hard material expert Kenneth J A Brookes has died

Kenneth J A Brookes, a renowned hard material specialist, consultant, author and Powder Metallurgy industry journalist, has died.

Having begun his career at Tungsten Electric Company, London, in 1951, he was responsible for research and technical innovation aimed at a range of submicrometre hardmetal grades (including special alloys for machining superalloys) with chromium-carbide grain-growth inhibition; highly-alloyed, extra-tough, heat-resistant, solid-solution carbides; consistently super-dry hydrogen to minimise grain growth; nanosize cobalt to eliminate binder lakes in sintered hardmetal; and a special-purpose ultra-hard (2250 HV30) grade with 7% cobalt.

On leaving Teco, Brookes published the widely consulted *World Directory and Handbook of Hardmetals and Hard Materials*, which was first published in 1975. The production of this extensive and informative book ensured that Ken made contact with a fully representative community of companies active in the field, thus providing a thorough overview of their many interests.

Brookes was a regular attendee at most of the hard material communities' events, such as the Plansee Seminars, Euro and World PM meetings and the International Science of Hard Material conferences. In 2017, he received a special Lifetime Service Award, presented at Euro PM2017 in Milan, Italy, for his highly regarded contributions and association with the hardmetal and hard material community over an extremely long period.

Brookes also had a parallel career with senior responsibilities in journalism, being a former president of the UK Chartered Institute of Journalists. For sixty-nine years Ken Brookes took a special interest in promoting the wellbeing and success of the hard materials sector.

He will be missed by many in the industry.

Ken Brookes received a special EPMA Lifetime Service Award in 2017 (Courtesy EPMA)

Waygate Technologies launches next generation Phoenix V|tome|x S240 CT system

The V|tome|x S240 covers a wide range of CT applications (Courtesy Waygate Technologies)

The new V|tome|x S240 is said to cover a wide range of CT applications in research institutes and industrial quality labs, including internal defect analysis, 3D quantitative porosity analysis, materials structure analysis, assembly control, and coordinate measurement tasks such as CAD data nom/act comparison.

Reported to maintain its industry-proven, optional combination of both a nanofocus and microfocus X-ray tube, the new system is equipped with the Dynamic 41|200p+ detector technology that allows for higher resolution and image quality at much faster scan times. This proprietary device is well established with the premium system V|tome|x M. It doubles CT throughput at the same quality level as conventional DXR detectors by combining increased detector sensitivity and a larger imaging area, with faster frame rates and adaptive imaging modes.

By concentrating more power on a smaller focal spot, the optional High-flux|target offered by Waygate Technologies doubles resolution or scan speed. Production throughput can thus be increased even further without compromising on accuracy and precision, the company states.

The Phoenix V|tome|x S240 is capable of helical or spiral scanning with the sample moving upwards in the X-ray beam, thereby enabling faster scans of longer parts, and eliminating the need to stitch several partial scan results together afterwards. This acquisition technique is claimed to generate significantly better results by eliminating artifacts on horizontal surfaces and in the stitching areas.

The system is equipped with an advanced, highly intuitive CT scanning software for fully automated data acquisition and volume processing. In production mode, the entire CT scanning and evaluation process chain can be initiated, with 3D failure analysis or 3D metrology tasks executed automatically.

www.waygate-tech.com

EPMA announces the 2020 Fellowship Award and Distinguished Service Award winners at Euro PM2020

The European Powder Metallurgy Association (EPMA) announced the recipients of its annual Fellowship Award during the opening session of Euro PM2020, held this year as a digital event from October 5–7 due to the ongoing coronavirus pandemic. The EPMA Fellowship Award recognises individuals in the scientific and/or academic community for significant contributions to the development of the PM industry.

Announcing the awards, EPMA president Ralf Carlström stated, "The EPMA fellowship is a fantastic recognition from the PM community for tremendous work and continued involvement in PM science and technologies."

"This distinction has received massive support from the EPMA council, as the contribution of academia and scientists involved in PM has been key for the development of the PM industry. It is essential for our future," he added.

The recipients of the 2020 Fellowship Awards were:

Professor Dr Elena Gordo, University Carlos III of Madrid, Spain
Professor Dr Elena Gordo holds a degree in Mining Engineering and a PhD in Materials Engineering from the Technical University of Madrid, Spain. She is currently Full Professor at the University Carlos III of Madrid, where she is responsible for the Group of Powder Technology.

Professor Dr Elena Gordo received the 2020 EPMA Fellowship Award (Courtesy EPMA)

Professor Dr-Ing Frank Petzoldt received the 2020 EPMA Fellowship Award

With twenty-five years of experience in teaching and research, Prof Gordo has appointments at the National Centre for Metallurgical Research (Spain), the University of Nottingham (UK), London & Scandinavian Metallurgical Co (UK), the University of Cambridge (UK) and the University of Queensland (Australia).

Prof Gordo has more than 100 publications in journals indexed in SCI, with her main research areas currently being the design and production of alternative compositions for the hard materials industry, low-cost PM Ti alloys and the preparation of powders for Additive Manufacturing, among others.

Professor Dr-Ing Frank Petzoldt, Fraunhofer IFAM, Germany
Professor Dr-Ing Frank Petzoldt studied physics and received his doctoral degree from Technical University Clausthal in Germany. He has been working with the Fraunhofer Institute for Manufacturing Technology and Advanced Materials (IFAM) in Bremen since 1984, in a variety of positions.

In 1993, Professor Dr Petzoldt became Head of the Powder Technology Department at IFAM and in 1999 was appointed Deputy Director of Fraunhofer IFAM.

Professor Dr Petzoldt has over 100 publications in international journals and conference proceedings, and is a Consulting Editor for PIM International magazine. He is lecturer both at the University of Bremen and the University of Applied Sciences in Bremerhaven and was appointed to professorship in 2013.

Philippe Gundermann received a 2020 Distinguished Service Award (Courtesy EPMA)

Steve Moseley received a 2020 Distinguished Service Award (Courtesy EPMA)

Distinguished Service Awards

The EPMA also announced the recipients of its 2020 Distinguished Service Award during the opening session of Euro PM2020, held this year as a digital event from October 5–7 due to the ongoing coronavirus pandemic.

Since 1998, the EPMA's Distinguished Service Awards have been presented in recognition of indi-

viduals who make an outstanding contribution to the European PM industry. Recipients are selected by the EPMA Council and receive their award at the association's annual congress.

This year, the Distinguished Service Award was presented to Philippe Gundermann and Dr Steven Moseley.

Philippe Gundermann, VP Strategy and Investor Relations, Eramet

With a metallurgical engineering background, Philippe Gundermann has held various technical and managerial positions within France's ERAMET Group since joining in 1993. He began in the nickel-cobalt Sandouville Refinery as Principal Process Engineer, and after the development of new recycling activities he took over the R&D and Investment Management for this division. He was later involved in the industrial strategy of the Nickel Division at ERAMET, particularly during the first stages of the major industrial programs in New Caledonia.

From 2003 to 2007, Gundermann was CEO of Eurotungstene, a 100% subsidiary of ERAMET, leading the team and developing new powder products and metallurgical businesses in the competitive international metal markets, with a specific focus on Asia.

In 2007, Gundermann was appointed CEO of Aubert & Duval and ERASTEEL, a position he held for six years. From there he was appointed Executive Vice President Strategy and Innovation, Investor Relations, and is now also responsible for the overall supervision of research and engineering activities for the ERAMET Group.

In addition to his work at ERAMET, he is involved in a number of professional organisations, and has been president of the EPMA and a board member of A3M (Mining, Minerals and Metals Alliance).

Dr Steven Moseley, Chief Scientist (Hard Materials) and Key Expert (Inserts Development), Hilti AG

Dr Steve Moseley holds a bachelor's degree and PhD in Metallurgy from the University of Sheffield, UK, and has worked in the field of Powder Metallurgy since 1987. Following research work on the HIPing of ceramic-metal powder composites, he spent three years in the steel industry before returning to PM as Technical/Quality Manager for a UK-based hardmetal manufacturer.

Since 1996 he has worked at Hilti AG in Liechtenstein, primarily on the development of cutting materials, joining technologies and drilling systems, covering cemented tungsten carbide hardmetals, diamond impregnated segments and polycrystalline diamond. His current position is Key Expert and Chief Scientist within the Business Area Electric Tools and Accessories.

Dr Moseley is a Council Member of the EPMA and co-chairman of the European Hard Materials Group (EuroHM).

www.europm2020.com

Höganäs works to minimise climate impact on the way to a sustainable future

With climate change an increasingly important focus globally, metal powder manufacturer Höganäs AB, Höganäs, Sweden, is focusing on minimising its climate impact in order to achieve its ambitious goal to become climate neutral by 2045. The company's soft magnetic composites, with their use in the production of more efficient magnetic circuits, can also help its customers reach their own climate goals, Höganäs reports.

"The climate change issue is becoming increasingly important and we are convinced that our climate work will strengthen our competitiveness," stated Nicklas Lång, Senior Vice President Sustainability at Höganäs. "For example, since automotive manufacturers have ambitious climate goals, as part of the same transition, we can help our customers meet their requirements. Using metal powders in production is already a resource-efficient method, and now our ambition is to take this a step further by offering climate neutral and more sustainable products."

Höganäs has long worked on energy efficiency and the reduction of its climate impact; developing products that contribute to electrification, purchasing renewable electricity, investing in solar cells and supplying waste heat from production to local communities – just to name a few examples.

"The purpose of our climate goal and our Climate Roadmap is to clarify the focus of our priorities in order to have the greatest possible impact," explained Lång. During 2019 and 2020, a project has been ongoing at the company for the purpose of gathering information about possible solutions to lower carbon emissions and find the most effective path going forward. The project also includes the mapping of indirect, scope-3 emissions [1] and creation of models for Life Cycle Assessments on products.

"For this reason, our ambitious long-term climate objective not only includes our own emissions, but also emissions caused by our purchases of raw materials, products and electricity," Lång noted. "But we know that we are dependent on social progress within several sectors in order to reach our climate goal. For example, we need the opportunity to buy electricity with a low carbon footprint, which is a major challenge in some countries. Access to renewable fuels and materials, such as bio-charcoal and biogas, and climate-friendly transport modes are other challenges. But we will see what we can do ourselves and what we can do in partnership with others. We also need to develop new knowledge through both our own research and research through our collaborations."

Fig. 1 Höganäs has worked hard to lower the environmental impact of its metal powder production across its site in Höganäs, Sweden (Courtesy Höganäs)

Substantial reductions in energy consumption

One area where Höganäs has seen significant progress in recent years is the reduction of energy consumption at its production plants in Sweden, which account for 60-70% of the company's total production in terms of volume. Since 2005, the kilowatt hours required per tonne of product has been reduced by 23%. This was possible by the introduction of a third-party certified energy management system in 2005, followed by a comprehensive energy audit of the entire operation.

"From this, we could identify the main uses of energy, and start setting targets for the areas that really mattered most," explained Magnus Pettersson, Energy Coordinator, Höganäs. "Ever since, we have been committed to continuous improvement. Every year, we set targets and conduct reviews, and are always looking for new things we can do to reduce energy consumption further."

One of the earliest and most effective measures taken as a result of the energy management system and audit was to optimise the fuel/air ratio on the burners Höganäs uses for heat treatment. While the energy savings for each individual burner were minor, the combined effect from all burners resulted in a total energy saving of nearly 10%.

"At the beginning of the project, we started out with the larger, simpler measures, and then over the years, we have focused more on the smaller details to continue generating savings," Pettersson continued. "Hopefully, we can reduce our energy consumption by another 10% over the next ten years by continuing to take small measures. But I think the big opportunities for us will come as we build new plants and modernise our equipment. This will give us the chance to invest in newer, more efficient equipment and really make big improvements. Expanding the use of efficient metal powders is not only an improvement in itself, it will give us the opportunity to improve the production further through new investments."

Fig. 2 Nicklas Lång (left) Senior Vice President Sustainability at Höganäs and Lars Hultman (right) who works in business development for electromagnetic applications (Courtesy Höganäs)

Shifting towards renewables

In addition to reducing energy consumption, another key priority for Höganäs is sourcing more energy from renewable sources. One example is its collaboration with Swedish startup Cortus Energy, which has seen the companies partner on the construction of a unique plant for the production of renewable gas from forest residues, which can replace fossil natural gas. The technology was developed by Cortus Energy and is now being tested on an industrial scale at Höganäs (Fig. 3).

"If this demonstration project proves a success, we will be able

to use the new biofuel to replace 15–20% of the natural gas we currently use," noted Pettersson. "And if it continues to be successful over the coming years, we could potentially replace all the natural gas we consume."

When it comes to meeting Höganäs' goal of being climate neutral by 2045, a big challenge will be to find renewable forms of carbon. Currently, several ongoing projects are looking into how different forms of charcoal could be used to replace fossil carbon, as well as how Höganäs' processes can be adapted.

"You cannot make steel without carbon – somewhere, somehow, it needs to be added – so we need to find a renewable source in the next 20–25 years," Pettersson explained. "We have done full-scale production of atomised steel grades based on renewable coal that we have added to the electric arc furnace. The problem is the availability of these coals and finding suppliers that are able to provide the amount we require at the grades and qualities we need, in a sustainable way. But we are working on building up a sustainable supply chain with the correct specifications for our processes."

Soft magnetic materials: part of the solution

In addition to reducing its own climate impact, Höganäs believes its products can help its customers and society as a whole to make the transition towards a climate-neutral future. Powder Metallurgy is a resource-efficient technology in its own right, but new products and applications can provide further improvements. Soft magnetic composites (SMCs), for example, can help meet the high demand for efficient energy solutions.

"We were a little ahead of our time and started developing soft magnetic iron powder as early as the 1990s. But, we persevered, and now we can see interest in the market for this technology," said Lars Hultman, who works in business development for electromagnetic applications at Höganäs and is one of the company's experts in the field.

Soft magnetic composites have a specific property: they are easy to magnetise, and they increase the strength of an applied field. The fact that the material can carry a 3D-flux enables the design of improved and more efficient magnetic circuits, contributing to more efficient and compact electric motors and inductors; the latter are used, for example, in inverters in solar and wind power. Hultman explained: "Solar cell panels produce direct current, but the electricity grid we are connected to is an alternating current. This is why inverters are needed to convert the direct current, and high-efficiency inductors are a

necessity in these units."

A large portion of the global electric and hybrid car industry is an important target for Höganäs' soft magnetic iron composites. Example applications include electric drive motors and smaller electric motors for automotive electrical systems, such as electrical parking brakes. Other important applications for the future include water and oil pumps, which are powered by electric motors in modern cars. Similarly, iron powder can also be used in the electric motors found in our homes – in everything from vacuum cleaners and fans, to refrigerators and heat pumps.

"Components manufactured with Powder Metallurgy can, among other things, accelerate the development of future energy systems and technology for transport solutions. We have many innovative customers who manufacture products that are needed to make this sustainability journey," said Hultman.

First steps into the automotive industry

One of Höganäs' breakthrough customers when it comes to the application of soft magnetic composites in electric motors is YASA Limited, a British manufacturer of electric motors and motor controllers for the automotive industry. YASA currently uses components made from Höganäs' soft magnetic composite Somaloy® in its axial-flux electric motors. Until recently, it had mainly focused on manufacturing high-performance engines for exclusive sports cars such as Ferrari.

"YASA's success is an important reference project that can make it easier to reach the mass market. The big car manufacturers are interested in improved electric motors, both with technology similar to YASA's but also the technology used in electric cars with more 'traditional' electric motors, and the trend here is to increase the motor rpm in order to downsize the complete electric drive unit," Hultman noted. "Here we see a clear advantage with soft magnetic composites, as our materials become increasingly competitive at higher rpm and higher electric frequencies. We are often invited to discussions with the car manufacturers and they appreciate our cooperation, so there are definitely opportunities for Höganäs, even if it does not happen overnight."

Fig. 3 Höganäs has collaborated with Swedish startup Cortus Energy, which has seen the companies partner to construct of a plant for the production of renewable gas from forest residues, which can replace fossil natural gas. The bio-gas technology is being tested on an industrial scale at Höganäs (Courtesy Höganäs)

[1] The GHG Protocol Corporate Standard classifies a company's GHG emissions into three 'scopes'. Scope 1 emissions are direct emissions from owned or controlled sources. Scope 2 emissions are indirect emissions from the generation of purchased energy. Scope 3 emissions are all indirect emissions (not included in scope 2) that occur in the value chain of the reporting company, including both upstream and downstream emissions. https://ghgprotocol.org/sites/default/files/standards_supporting/FAQ.pdf

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Arcast: A decade of innovation and a bright future for metal powder atomisation

Arcast Inc. celebrated its tenth anniversary in 2020. From its base in Oxford, Maine, USA, the company designs and supplies a range of atomising systems to a diverse customer base across the globe. Soon becoming a leader in compact, laboratory-sized systems, the company today has expanded to offer large scale, custom-built atomisers. In this article, we look at how the company has advanced over the last ten years, the key technology it has developed and what the future holds for this growing company as it continues to offer metal powder atomisation solutions to a wider market place.

With the COVID-19 pandemic having a major impact on global markets in 2020, it is no surprise that many in the Powder Metallurgy sector, from parts producers to powder makers, have had to cut back and adjust their operations in the face of reduced demand. There are a number of businesses, however, that have been fortunate, and have managed to buck this trend. After being in business for just over ten years, Arcast is one such company; currently, it is having one of its busiest years on record, with sales volumes and revenues reported to be higher than ever. Inevitably, some COVID-related difficulties have impacted production, but the company has been able to adjust for these and keep its head well above water.

Arcast began as a small fabrication and machine shop working out of an overgrown garage. This came from O'Neal's Manufacturing, owned by Rayland O'Neal, now president of Arcast; Sasha Long, the company's Corporate Officer and Engineering Manager, has known O'Neal since their school days, and joined Arcast at its inception. The company now operates out of three buildings with about 30,000 ft^2 of manufacturing floor space. This is split between machine shop, fabrication and assembly areas, as well as facilities for testing, material processing, laboratory and offices. Arcast has additional premises at its disposal that will allow for expansion in the foreseeable future.

Both O'Neal and Long worked in other industries before the launch of Arcast. With a background in general manufacturing, radar, TV and radio

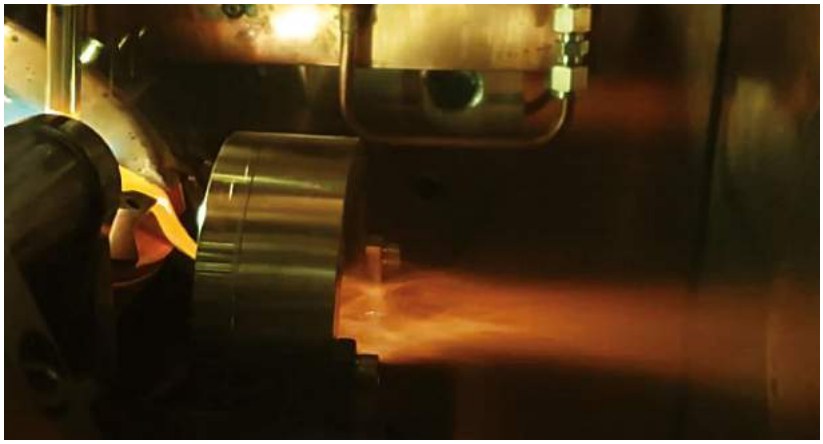


Fig. 1 Atomising in the Arc 200 (Courtesy Arcast)

Fig 2 Arcast's first Arc 200 (left) and, ten years later, the current Arc 200 (right) (Courtesy Arcast)

broadcast equipment (RF) engineering, and Long's additional work in the vacuum equipment industry, it was not a huge step to producing specialist furnaces and equipment for processing metals. In fact, this diverse engineering and manufacturing background has been the key to Arcast's ability to bring unique solutions to the challenges faced in this market.

The Arcast team creates the concepts, carries out the engineering, machines the parts, builds the chambers, tests the systems and processes material. With certified welding, professional engineers, UL-listed panel building, and certification to ISO9001 and AS9100 quality standards, the Arcast team and trusted contractors are able to produce effective solutions for its customers' needs. The company takes pride in seeing the product through from start to finish, and, where possible, undertakes everything in-house, giving it the best control over quality and allowing for quick changes as needed.

While the company's base is in Oxford, Maine, USA, its customer base is global. For the first five to seven years, most of its sales were in Europe, with a few in the USA, South Korea, India, Egypt, Australia and elsewhere. Over the past three years, the US and Canadian markets have opened up significantly, and there appears to be a substantial increase in the budget allocated to develop AM applications and other material research and development. Europe seems to have had a head start in this area, but the Americas are now picking up the pace. Arcast is also seeing increased interest in South America and Australia.

"What used to be a good order book at $10,000–100,000 a month has increased by an order of magnitude and is now between $100,000 to over $1 million a month..."

Over the past few years, the scale of projects has increased both in budget and in physical size. What used to be a good order book at $10,000–100,000 a month has increased by an order of magnitude and is now between $100,000 to over $1 million a month. This shows a real increase in the size of the market; a decade ago, gas atomisers sold by the handful a year, across the whole market. Nobody would have predicted that it would be possible for ten to twenty atomisers to be sold by a single supplier in a year, but this is what Arcast is now seeing. The company used to sell more arc melters and induction furnaces than atomisers, but with multi-use systems, the demand for powder research and AM grade powder production growth, the demand for gas atomisers has grown dramatically.

Building on the original arc furnace

The Arc 200

Arcast's first system was the Arc 200 cold crucible arc furnace (Fig. 2). This versatile furnace, with options to melt and cast in several different ways, became the foundation for many other products. The addition of gas atomisation capabilities (Fig. 3) and electromagnetic stirring made the Arc 200 a 'go-to' product for any growing material research lab.

With over forty units of the Arc 200 having been sold to leading universities, national laboratories, research establishments and industrial customers around the world, it has become a standard tool for alloy development and powder research, used both for consolidating powder produced in large production into buttons for analysis, and for core research on turning new alloys into powder.

With the Arc 200 as a core product, Arcast was awarded multiple Small Business Innovation Research (SBIR) research grants by both the US National Science Foundation for developing alloys and atomising methods, and NASA for cold crucible melting and alloying of shape memory alloys. These grants resulted in a leap ahead in atomising and melting technology, and several products resulted from the research funded.

Fig. 3 The Arc 200 with gas atomiser option (Courtesy Arcast)

VersaMelt gas atomiser

One such product to emerge from this research is the VersaMelt gas atomiser, developed in collaboration with The Université Catholique de Louvain (UCL) in Belgium (Fig. 4). Designed to be as compact as possible with a footprint of just 3 x 3 x 3 m, the VersaMelt atomiser offers four different kinds of melting

Fig. 4 The VersaMelt atomiser installed at UCL (Courtesy Arcast)

Fig. 5 The Arc 500 offers 100 kW of melting power and can perform the tasks and modes of operation as the Arc 200 more rapidly and at a larger scale (Courtesy Arcast)

arrangement, accommodated within one system:

1. Induction melting of a meltstock contained conventionally in refractory ceramic
2. Induction drip melting from a rod or wire feedstock (known as EIGA)
3. Cold crucible tilt-and-pour arc melting
4. The new development of plasma arc melting of feedstock delivered via a tubular feed system.

This versatility allows the VersaMelt to process a wide range of metals/alloys of varying physical forms, the particular melt option chosen depending on which is most suitable for the intended alloy and its physical form. The VersaMelt offers a range of material processing options for powder production in one machine, enabling UCL to produce the widest possible range of novel alloy powders to support its growing AM research centre. UCL is the first of several to have acquired this capability; Center for Additive Manufacturing and Logistics (CAMAL), North Carolina State University (NCSU) and the Center for Manufacturing Research of Tennessee Tech are Arcast's most recent VersaMelt customers.

The plasma arc tube feed atomisation that Arcast developed is one of the newest forms of melting and atomising on the market. It is offered in the VersaMelt and as a production system, and accepts any material that can be fed through a tube, where it is melted and atomised from a cold crucible hearth. This means there is no contamination from the system itself (no ceramics). Almost any metal can be processed and in almost any form, provided it can be fed down the tubular feeder. The system can accept feedstock in the form of wire, rod, chip, sprues, pellet, oversize powder or similar forms. "This versatility is a game changer for many customers and for the industry. It takes the advantages of the well-known EIGA method and multiplies them because of the flexibility of melt stock," explained Long.

The Arc 500

As popular as the Arc 200 and VersaMelt have been, many customers require other options and larger capacity for laboratory-scale systems. In response to this demand, Arcast has introduced a larger Arc 500 model (Fig. 5). With 100 kW of melting capacity, much larger samples and larger batches of powder can be produced.

Large-scale bespoke atomisers

While Arcast has been leading the way in research and laboratory-scale gas atomisers, this has not been the company's only achievement over the past ten years. Many industrial and research customers have benefitted from larger-scale atomisation systems with capacities of hundreds of kilograms. Customers for these units include Uddeholm (Sweden) and the Royce Translational Centre (RTC) at the University of Sheffield (UK). The most recent installation of a larger atomiser is at the research establishment CEIT, Spain (Fig. 6).

"These production systems have grown from the experience of

Arcast and working closely with our customers. We look forward to continuing to work with CEIT to develop new materials and atomising processes," Long stated. "They have the base Arcast design for a close-coupled gas atomiser. This is a standard design intended to perform over a wide range of materials and process settings."

CEIT has an advanced ability to design and model atomising gas jets/dies to optimise atomiser performance targeted for specific applications, an example of the type of collaboration Arcast enjoys with customers and researchers. "We will be working closely with CEIT to help them develop the atomiser parameters and equipment design to optimise performance," Long continued. "We will be addressing: gas efficiencies, particle size distributions (both narrower and broader), cooling rates and other process parameters. These developments are aimed at improving the understanding and performance of powder production, from which the entire industry may benefit. This is Arcast's approach to all of our products. We are always looking to improve. We are open to working with industry and research leaders to obtain the best results."

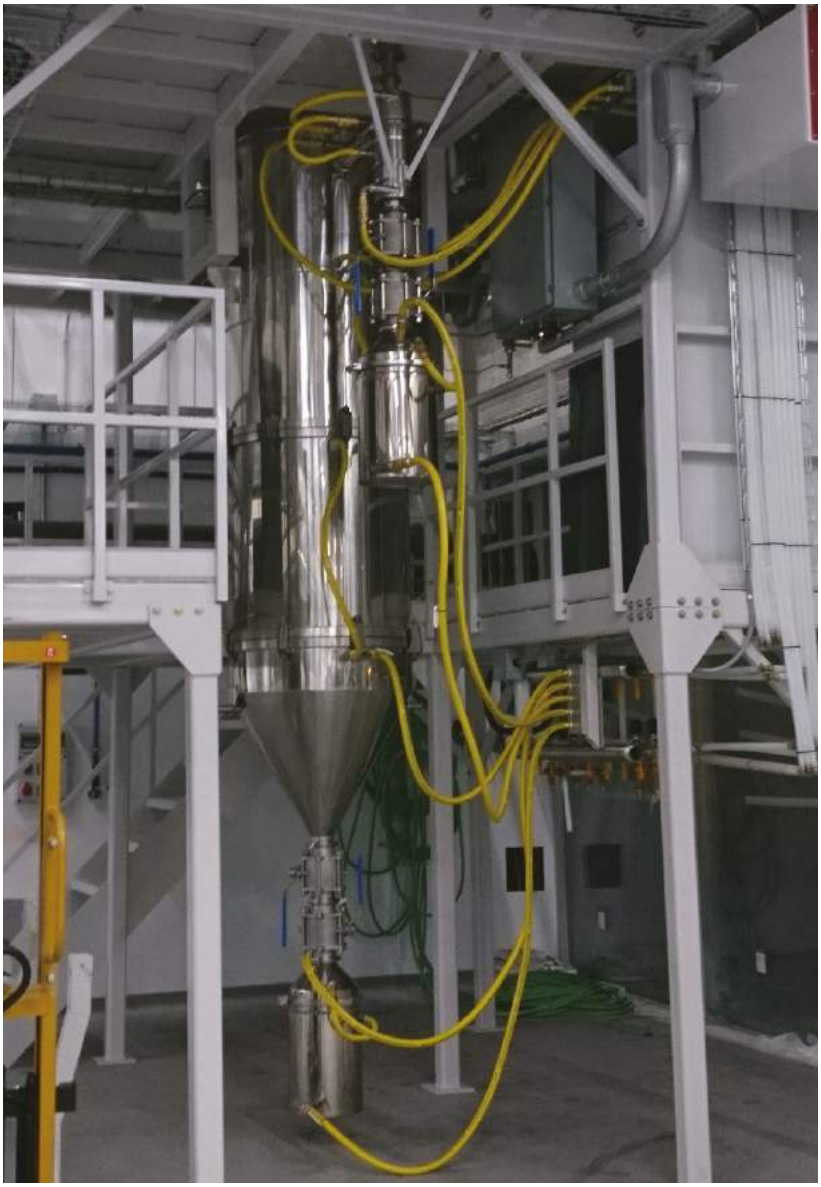


Fig. 6 The new inert gas atomiser installed at CEIT Spain (Courtesy Arcast)

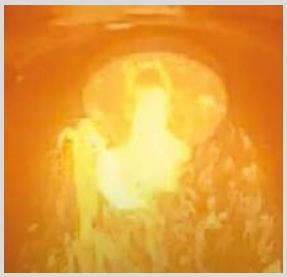
Working with reactive metals

Arcast has also been working with leaders in the processing of reactive metals such as aluminium, magnesium, zirconium, uranium and others. Many of these materials are highly reactive in powder form, and present an explosion risk during atomising and in post-atomisation handling. "We work closely with the experts in the field of dust explosions," Long explained. "Through this work, we have developed an in-depth understanding of the risks and hazards of explosive powders. This work has resulted in designs for atomising these materials in the safest possible way. With multi levels of redundant protection and engineering reviews, we deliver a product our customers can have confidence in."

"All hazard elements are considered, and where possible, mitigated," continued Long. "We go over and above national codes where standard models and calculations are inadequate or do not fully recognise the conditions or hazards that occur in metal gas atomisation. We consider possible pressure piling and high-speed monitoring of potentially dangerous process conditions. We design systems that can withstand an explosive event even during the opening of the system to atmosphere. These safety systems have taken many years to develop, and our designs have been reviewed by many professional engineers; we have enlisted the help of experts that sit on the NFPA board and the scrutiny of national laboratories. We want the highest assurances that our customers receive the safest designs possible."

In ten years, Arcast has captured a significant share of the market for laboratory-scale alloying, casting and atomising equipment. It has also developed competitive production systems with novel processing options to advance the field of Powder Metallurgy.

Induction drip melting atomisation from a rod or wire feedstock (EIGA)



Close-coupled atomisation is designed to perform over a wide range of materials and process settings

Fig. 7 Common methods of gas atomisation in Arcast atomisers; (left) EIGA and (right) close-coupled (Courtesy Arcast)

Processing of non-standard and custom powders

While the equipment side of Arcast's business has been growing and demand is high, the material processing side of the business is still in development. "We quickly realised that some customers don't have the budget, expertise or facilities for atomising equipment of their own, but many still have a requirement for non-standard powders," explained Long. Recognising this opportunity, Arcast provides a toll service for melting, alloying and atomising powders for its customers. "We have at our disposal a number of atomising processes similar to those that we sell to our equipment customers."

The proprietary process used most by Arcast is HELGA. HELGA was first developed to process titanium alloy powders and is capable of producing as-atomised D50 values of 20-40 µm from scrap, bar, chip, over-sized or out-of-spec powder, compacts and many other feedstocks. It is also a completely clean process, with no ceramic contact involved. "The melting method used in HELGA, combined with the atomising method, is like no other process employed by others," Long explained. "It has taken nearly the full ten years that Arcast has been in business to develop HELGA, but we continue to improve its performance and efficiencies. Our material customers have benefited greatly from a process that can now produce powder from materials that could not be atomised before." Most conventional atomising or powder production requires metal to be melted in ceramic crucibles, or involves a step in which it comes into contact with ceramics in other forms, such as guide tubes, nozzles, etc. For molten materials that cannot be allowed contact with ceramics, feedstock generally has to be in the form of rod or wire. In some cases, the raw material is crushed and spheroidised (HDH).

A greater choice of feedstock

Using the HELGA process, a much greater choice of feedstock can be used. These include refractory metals, brittle metals and reactive metals that would attack ceramics. Amongst the materials that have been successfully processed using HELGA are titanium, boron, tantalum, zirconium, niobium and others (Figs. 8 & 9). "It would be foolish to claim a total panacea, but our experience is that HELGA out-performs other atomisation processes for the most difficult and challenging materials," Long stated. "HELGA is also extremely tolerant of a wide variety of feedstock physical form and is well-suited to processing scrap and recycled out-of-spec powder."

Developing MIM and AM grade powder

Arcast previously enjoyed considerable success in processing chemically-produced titanium sponge from Cristal Titanium, converting it into high- quality, low-contamination powders of good spherical morphology. This was until Tronox acquired the whole of Cristal's business and shut down the titanium sponge part of the operation. Since this change in direction, Arcast has been working with various other customers and partners to develop bulk production with high value alloys using the HELGA process. In several cases, it is working to license the method for special production of various alloy powders. The company sincerely believes that Arcast and HELGA can give customers a clear advantage in cost and quality. Direct routes to MIM and AM quality powder from challenging alloys is a game changer, and will open up many possibilities. Prior to Arcast's involvement, several of its customers had been trying, unsuccessfully, to make powder of the right quality and characteristics from their alloys. The company hopes to be a part of opening up new markets and uses for advanced materials.

"As part of our quality focus, Arcast obtained ISO 9001:2015 and AS9100D certification, so we assure our customers that we are meeting the highest standards. This also allows us to sell directly to the aerospace markets," stated Long.

Looking to the next ten years

Despite the setbacks imposed globally by COVID-19 in 2020, Arcast has completed, shipped, installed and commissioned at least eight small gas atomisers and seven medium- to large-scale atomisers in 2020, and reports that next year is looking nearly as promising. While many large powder producers are struggling with the impact of the pandemic, the demand for equipment is still very high, and research efforts in this field remain strong.

Arcast is also looking to further expand the powder production side of its business. To date, equipment sales and production have dominated the company's resources and endeavours, but have also been the key to funding and developing its advances in material processing. Now that the HELGA development has proven itself technically, Long explained that Arcast is keen for it to be grown and developed commercially.

"We are happy to work with customers to develop their materials and to target the AM, MIM and other Powder Metallurgy markets," he stated. "We believe we can provide a path to market for novel, advanced and challenging alloys: for them to be processed economically and customised for the unique application opportunities that AM brings. With a number of our customers and partners developing the understanding of how materials behave in AM applications and how best to build the parts in the various different AM printers, it is exciting to see the possibilities unfold. Arcast has striven to be one of the most dynamic and influential manufacturing companies in the industry. Its goal has been in producing solutions for processing challenging materials. In this, we believe we have had a real positive impact and will continue to do so."

By offering a range of unique products and working closely with its customers, Arcast has achieved an enviable customer base and a growing reputation. The advantages of Arcast products are now widely recognised, thanks to the many papers and articles that have been published by its customers; this is demonstrated by its receipt of the award for SBA Exporter of the Year in 2018.

"We are confident that Arcast can strengthen its position as the largest supplier of small and medium scale atomisers in the market," noted Long. "We wish to thank our customers for choosing us and for the patience they have displayed while we push through the unavoidable complications that all of us have had to endure this year."

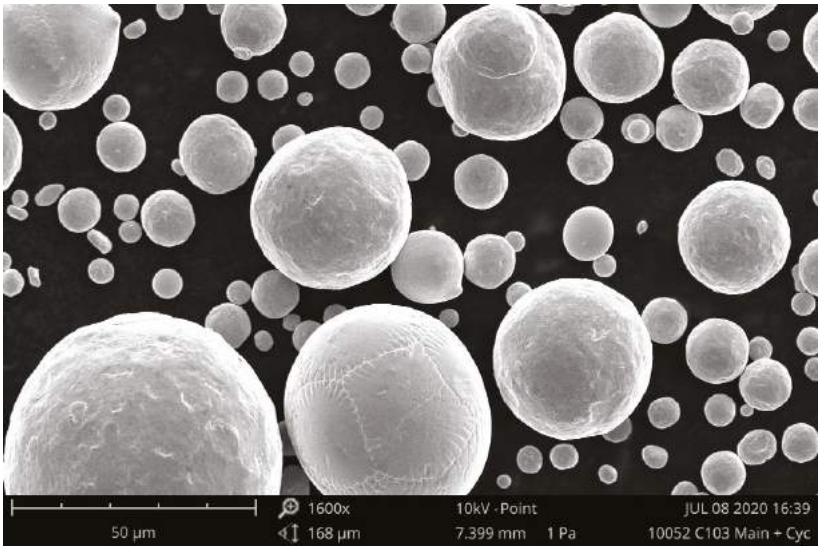


Fig. 8 Arcast's new scanning electron microscope highlights the quality of powder produced from HELGA. Here, as-atomised C103 Niobium Alloy can be seen. Note: this image has not been artificially enhanced (Courtesy Arcast)

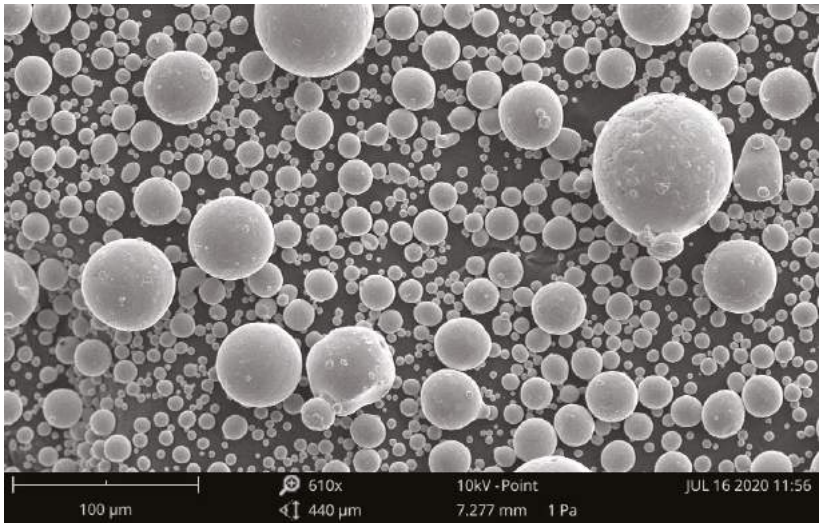


Fig. 9 As atomised ELI Ti-6Al-4V powder (Courtesy Arcast)

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Particle characterisation of metal powders with dynamic image analysis and laser diffraction

The size and shape of metal powders and metal alloys can be characterised by a number of different methods. The control of particle size and distribution is considered an important step in ensuring a metal powder meets the required quality levels. In this article, Kai Dueffels and Robert Waggeling of Microtrac MRB, Germany, discuss the particle characterisation methods of dynamic image analysis and laser diffraction, using the company's Camsizer X2 and Sync analysers.

This article will present several examples of how the size and shape of typical metal powders and metal alloys can be characterised by dynamic image analysis (DIA) and laser diffraction (LD) technologies, using the Microtrac MRB Camsizer X2 and Sync analysers (Fig. 1). The advantages of these instruments are short analysis times, excellent repeatability and 'infinite' resolution. In the case of image analysis, many different size and shape parameters are measured and reported, for each individual particle, and all data is available as soon as the measurement ends.

Shape parameters are calculated as ratios of various size measurements and are reported on a scale from 0–1. The data for each

Fig. 1 The Microtrac MRB Camsizer X2 (left) offers advanced dynamic image analysis. The Microtrac Sync (right) is a hybrid system that incorporates both dynamic image analysis and laser diffraction techniques

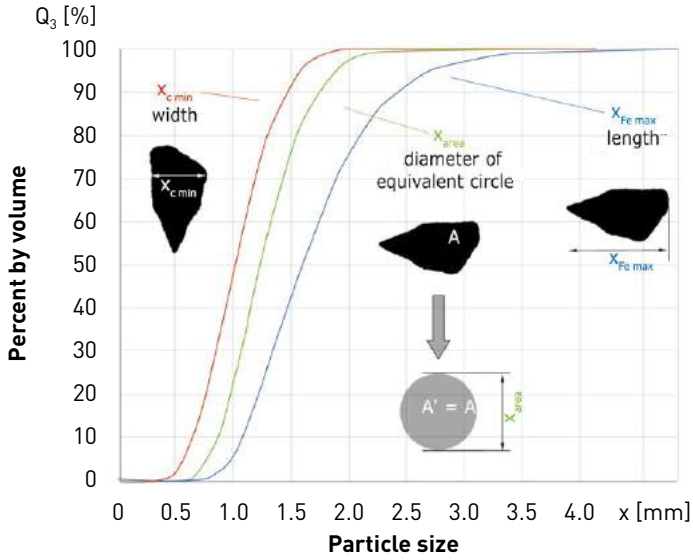


Fig. 2 Selection of Camsizer X2 basic size parameters used in image analysis. The size distributions are based on width (red), length (blue) or equal area diameter (green)

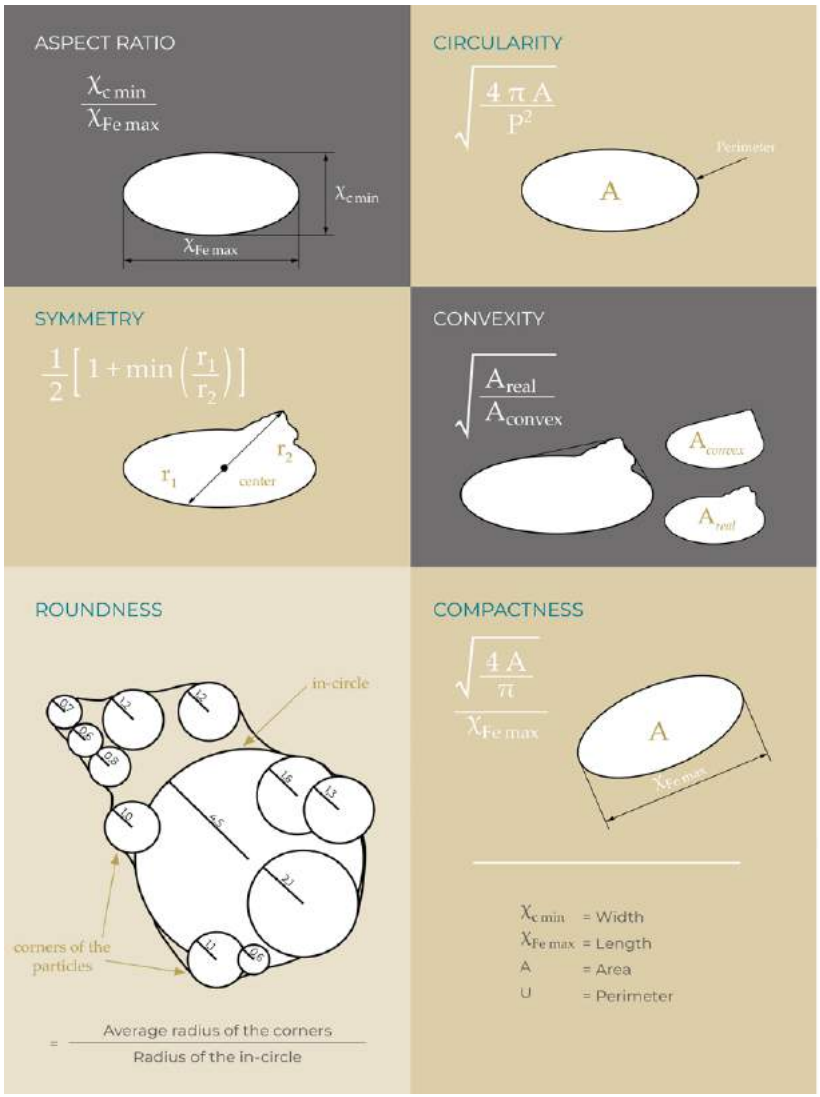


Fig. 3 Only image analysis provides information on particle shape

parameter can be reported in both frequency and cumulative distributions, in volume and number format, and the complete parameter data set can be reported for each individual particle.

Image analysis: What you see is what you get

Image analysis techniques provide a direct approach to particle size analysis. The basic idea is simple: 'What you see is what you get.' Automatic software algorithms determine size and morphology based on digital photographs of individual particles.

Camsizer X2: Dynamic image analyser

The Camsizer X2, with the widest reported dynamic range in the industry of 0.8 µm to 8 mm, can measure both suspensions or dry samples, using one of three different sample dispersion accessories. In Fig. 2, particle length, width and equivalent area diameter information from the Camsizer X2 are shown. A selection of shape parameters is explained in Fig. 3.

In the measurement set-up of the Camsizer X2 (DIA), particles move in front of a camera system, transported either by single pass air flow or recirculating in liquid. Thus, it is possible to obtain data from up to several millions of particles within a few minutes, especially when measuring dry. The results are based on a representative amount of sample material for both methods and are therefore statistically sound.

In Fig. 4, the principal set-up of the optics for the Camsizer X2 dynamic image analyser is shown. As the particles pass through the field of view, a light source illuminates the particles from one direction while a camera system takes pictures from the opposite side. A software evaluates the shadow projections of the particles to determine the size distribution of the sample with a high acquisition rate.

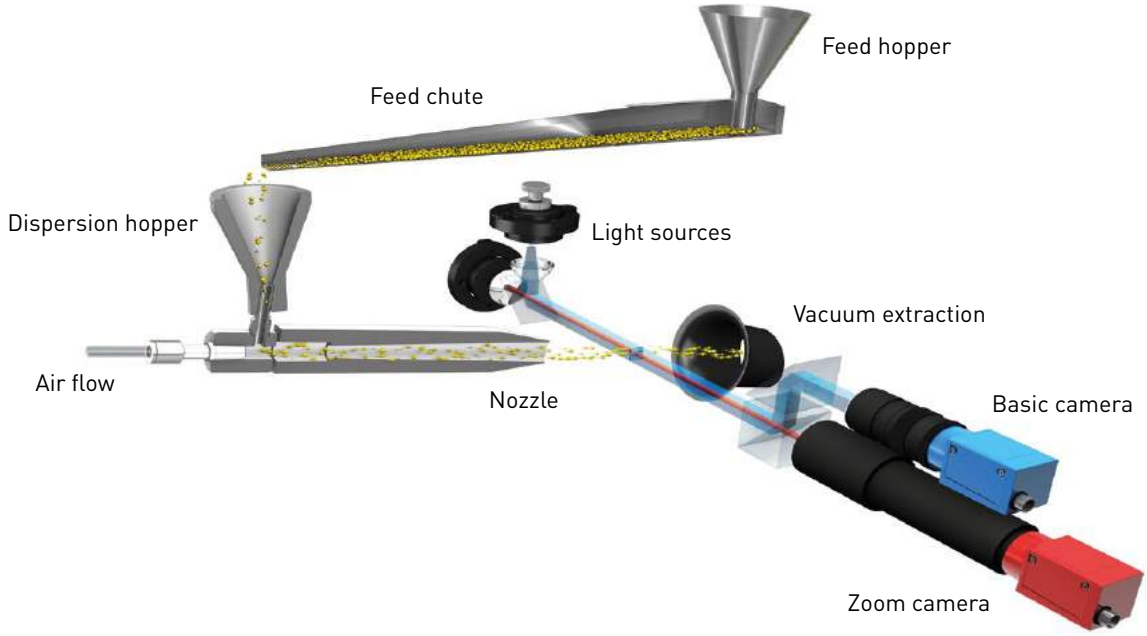


Fig. 4 Unique measurement principle of the Camsizer X2 for analysis of dry powders

A unique feature of the Camsizer X2 is the dual camera technology: two cameras with different magnifications cover a wide-measuring range. One camera with high magnification is optimised for the analysis of small particles (the Zoom camera), while a second camera with a lower magnification but wide field of view allows simultaneous analysis of the larger particles with high detection efficiency (the basic camera). The Camsizer X2 records more than 300 frames per second, with one single frame easily containing several hundreds of particles, depending on the sample size range.

DIA measures the particle size distribution and quantitative particle shape (percentage of round versus irregular-shaped particles, agglomerates, etc). Very small amounts of oversized, undersized, or irregular-shaped particles can be detected, to a percentage as low as 0.002%. DIA therefore enables the user to obtain a comprehensive and thorough understanding of size- and morphology-related sample properties. It is the ideal method for both research and development applications and quality control, being accurate, robust, sensitive and easy to use.

Wide range of materials, particle sizes and particle shapes

The following selection of application examples demonstrates the suitability of DIA to comprehensively characterise metal powders. Fig. 5 shows the results of the size analyses of ten different metal powders which are typical for Powder Metallurgy applications. Irrespective of the difference in chemistry, density, size and shape, all samples can be analysed with the Camsizer X2, using one instrument setup. An automatic feeding chute transports the sample to the analyser, where the particles are captured by an air flow. In this case, 50 kPa have been found sufficient to achieve thorough dispersion, i.e. separation of individual particles.

The samples show a variety of mean particle sizes between 10–50 µm, with different widths of distribution. In this example, the iron powder (Fe) is the coarsest whereas the steel powder (316-B) is the finest. The titanium powder is characterised by a very narrow size distribution. The shape diagram (Fig. 5) shows that the iron powder has the lowest aspect ratio (breadth/length), whereas the titanium powder has the largest share of spherical particles.

"Powder Metallurgy processes usually require a wide size distribution to make packing the powder into the die easier, by filling the void spaces between large particles with smaller ones..."

Powder Metallurgy processes usually require a wide size distribution to make packing the powder into the die easier, by filling the void spaces between large particles with smaller ones. An irregular shape is often beneficial for the sintering process because it increases the contact between particles. However,

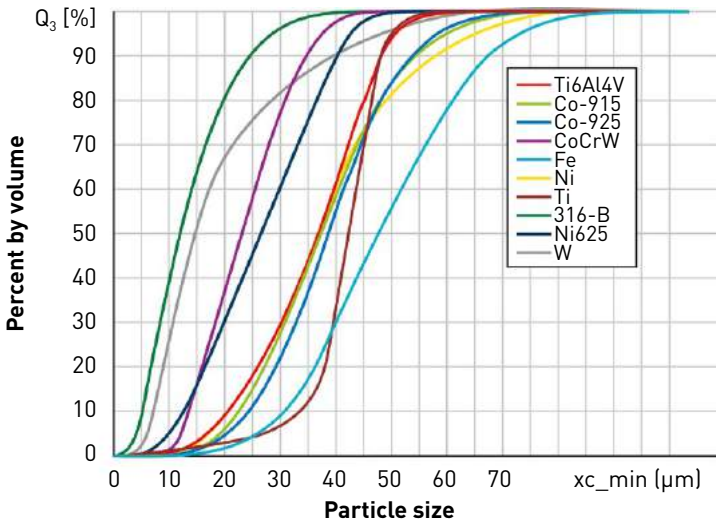
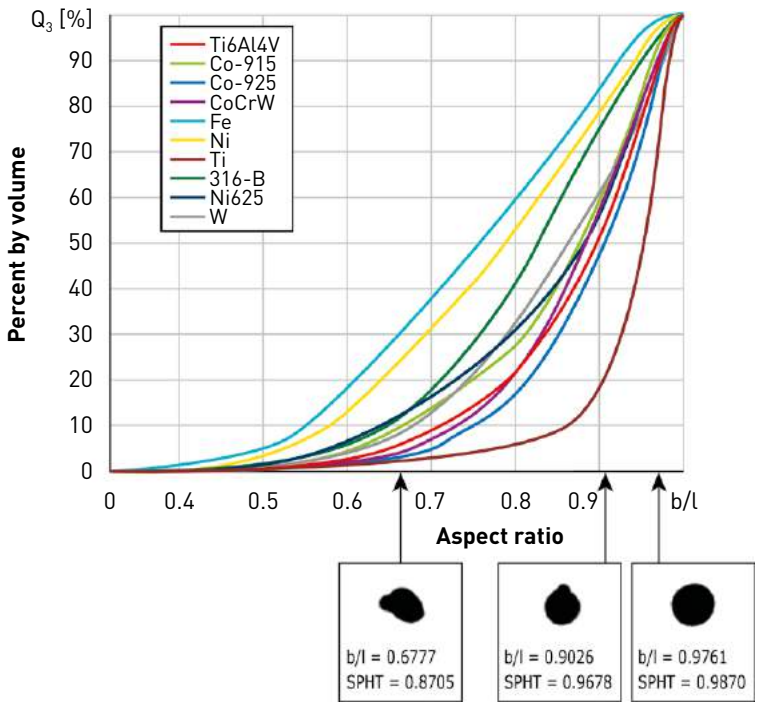


Fig. 5 Particle size analysis of ten different metal powders with the Camsizer X2. Direct measurement ensures accurate results



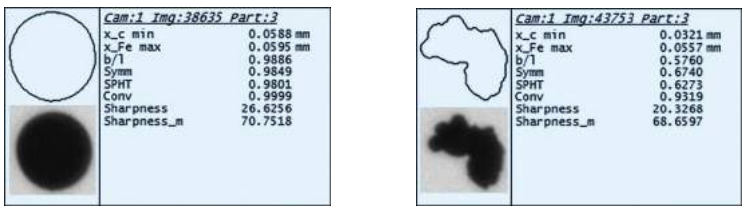


Image of a spherical metal powder particle

Irregular particles are reliably detected

Fig. 6 Analysis of particle shape in ten different metal powders with Dynamic Image Analysis (Camsizer X2). Beside the quantitative results, the recorded images allow an intuitive understanding of morphology and size differences. More spherical particles with higher aspect ratio plot on the right side of the diagram. Detecting the smallest amounts of irregular particles in a large quantity of predominantly spherical particles is a significant advantage offered by DIA

the particles must not be too irregular, as this will make compaction more difficult. In metal Additive Manufacturing (AM) for example, a spherical shape with a narrow size distribution provides a smooth layer of powder to ensure proper sintering and good metal parts. The average particle size is usually between 10–50 µm; hence, the titanium powder in the above example is suitable for AM. Oversized particles or very irregular particles need to be detected with great accuracy, since these are likely to cause defects in the finished workpiece. DIA reliably detects even small amounts of these undesired particles. Fig. 6 shows clearly just how easily DIA can identify defective particles.

Sync: Hybrid DIA and laser diffraction analyser

The novel Sync analyser is a revolutionary hybrid instrument which combines laser diffraction (LD) and DIA technologies in one unit, measuring the same sample in the same sample cell simultaneously. LD (a type of light scattering) technology has been used by the metal powder industries for decades as the *de facto* standard for measuring size distributions in outgoing QC certification by metal powder suppliers and incoming QC verification by Powder Metallurgy parts producers.

The optical bench of the Sync is shown in Fig. 7. Three lasers, available in blue or red, in combination with two linear diode detector arrays, allow the scattered light from the passing particles to be collected over a range of 163°. Smaller particles scatter light at higher angles and lower intensities than do larger particles. The Sync algorithm for LD back-calculates the particle size distribution that created the light flux distribution measured. Using a modified Mie theory, the algorithm compensates for non-spherical and translucent particles. Simultaneously, a rapid LED strobe lamp illuminates the particles and a set of optics

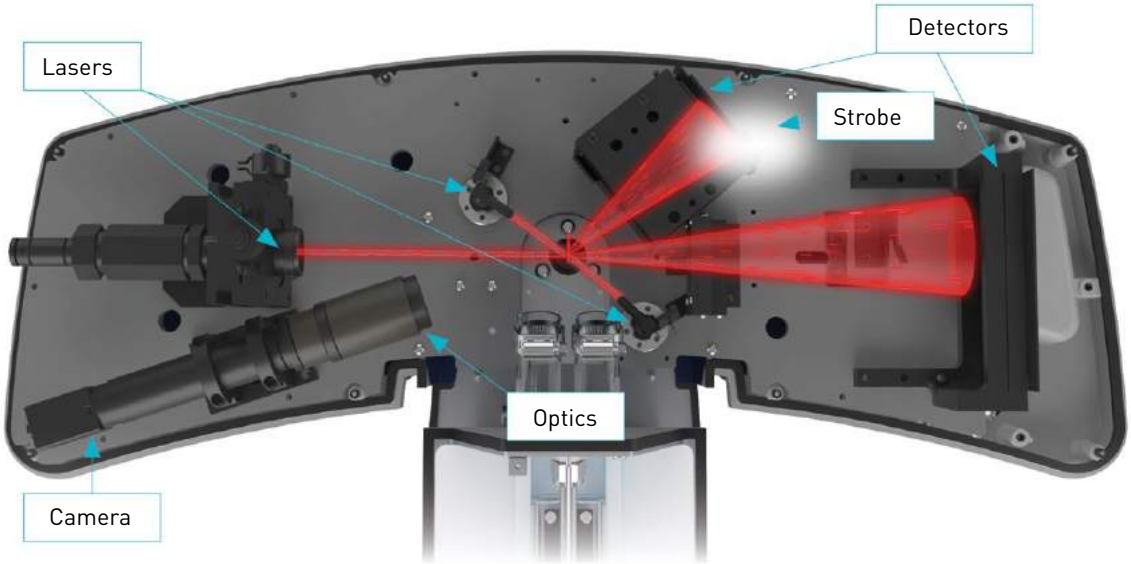


Fig. 7 Layout of the Sync optical bench, combining LD and DIA components

focusses the transmitted light for a digital camera to photograph the complete video file of the particle images, as the Camsizer X2 does, except that the Sync uses one camera.

The display shown in Fig. 8 is the LD size distribution report used by the metal powder industries. The DIA post-measurement software features a Particle Viewer display (GUI) and a Scatter Diagram display. These can be used to identify and quantify the percentage of agglomerates in the metal powder batch. This allows metal powder suppliers to recycle a bad batch (eg, too many agglomerates) before shipping to a customer, and allows parts producers to reject a bad incoming batch and avoid wasting time and money processing it.

Both the Camsizer X2 and the Sync can be relied on to quantify the agglomerates in a metal powder sample using two shape parameters. Size cannot be used, because these agglomerates exist throughout the size distribution. The shape parameters consist of a parameter that measures aspect ratio and one that measures how convex the outer boundary of the particle is.

An example using the Sync was evaluated, where the parameters used are the width to length aspect ratio (W/L aspect ratio) and solidity. A particle with a solidity of 1 is a particle with a completely convex outer boundary, with no concave indentations. A particle with a W/L aspect ratio of 1 would be a perfect sphere. In the Camsizer X2, the parameters are convexity (Conv) and breadth divided by length (b/l) respectively.

The search feature of the Sync software was used to isolate and quantify the agglomerates, which include all particles not within the red rectangle seen in Fig. 9. The agglomerates were found to make up 23% of the total sample by volume and 12% by number. This is key QC information for the PM industries.

Summary Data | Tabular Data | Notes/Warnings | Raw Data | Setzero | Size/Shape Data

Summary		Percentiles		Size percent		Peaks summary		
Data	Value	%Tile	Size (µm)	Size (µm)	%Tile	Dia(µm)	Vol%	Width
MV(um):	37.00	10.00	4.98					
MN(um):	1.625	20.00	9.50					
MA(um):	11.24	30.00	13.68					
CS:	5.34E-01	40.00	17.72					
SD:	25.55	50.00	22.01					
		60.00	27.42					
Mz:	28.74	70.00	35.23					
si:	31.06	80.00	48.22					
Ski:	0.552	90.00	78.91					
Kg:	1.754	95.00	127.0					

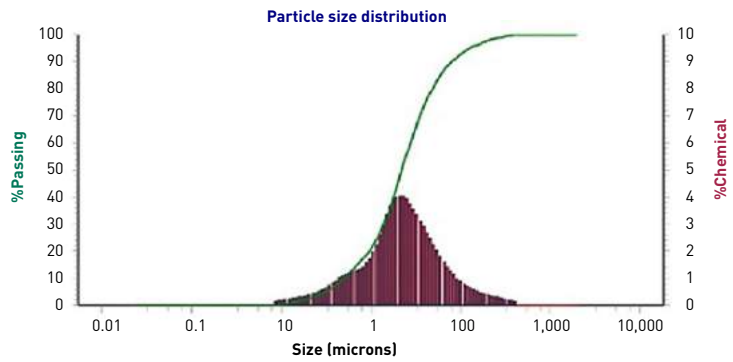


Fig. 8 LD particle size report from Sync, including percentiles, summary statistics data and frequency/cumulative distribution graphs

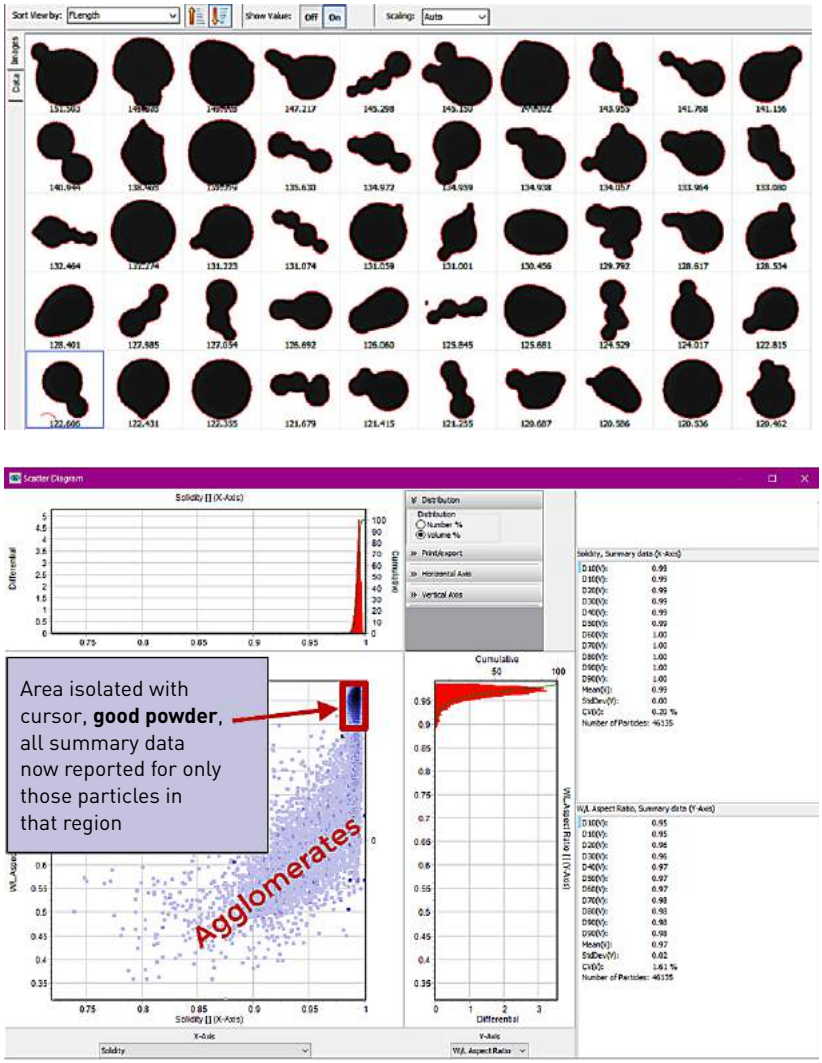


Fig. 9 Particle shape measurement of a metal powder sample with the image analysis function of the Sync. Images of agglomerates are visible on the top. The scattergram on the bottom allows a clear discrimination and quantification of agglomerates

Advantages of DIA and LD over other particle sizing techniques

For metal powders, mechanical sieve analysis is still used by some companies for particle size analysis. The absolute lower size limit for sieve analysis is defined by the smallest practically usable mesh size of 20 µm (air jet sieving), which is well above the average particle size of many samples for AM or MIM.

As a consequence, air jet sieving is not suited for the precise and reliable analysis of the whole size distribution of fine powders. It is often used for detecting the amounts of oversized particles with one sieve only, for example with 45 µm or 63 µm aperture size. Another drawback is that sieve analysis does not deliver any information on particle morphology.

The metal powder industries began replacing sieves with laser diffraction in the 1970s. Since then, laser diffraction has become widely used throughout these industries and is expected to remain the standard method for certifying and verifying particle size distributions. Laser diffraction analysers are easy to operate, and provide fast, robust results, and their technology and characteristics are well understood. Dynamic image analysis is finding rapidly growing use by these industries for morphological analysis to set QC specifications on shapes, to control properties that cannot be identified by size analysis alone.

Conclusion

With a number of Powder Metallurgy sectors, such as Metal Injection Moulding (MIM) and Additive Manufacturing, becoming more prevalent, there is an increased demand for specially designed metal powders with specific characteristics. Not only chemical composition, but also particle size & shape are of vital importance for the processability of powders. Depending on the application, the powder must meet a variety of specifications.

Laser diffraction size analysis for metal powders is embedded in these industries and expected to remain that way. Laser diffraction plus dynamic image analysis with the Sync, and DIA with the Camsizer X2, can provide all the relevant data on particle size & shape for metal powders. DIA, compared to electron/optical microscopy, measures a much larger number of particles and is therefore statistically more relevant and offers better reproducibility. One measurement only takes from one to three minutes, allowing for a high sample throughput and continuous quality control. For both powder producers and manufacturers of metal parts, the Sync and Camsizer X2 are precise, efficient tools which greatly improve the quality control process.

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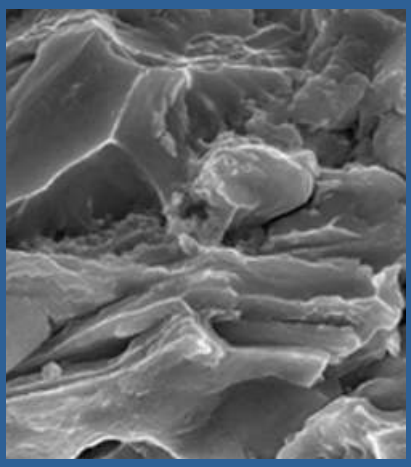

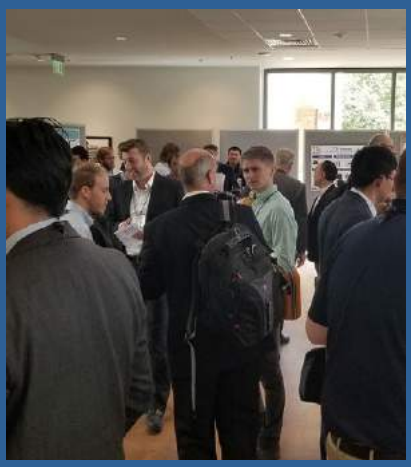

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After five successful conferences held in Australia, New Zealand, Germany, China, and the United States, PMTi is headed to Canada for the first time.

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International Conference on Injection Molding of Metals, Ceramics and Carbides

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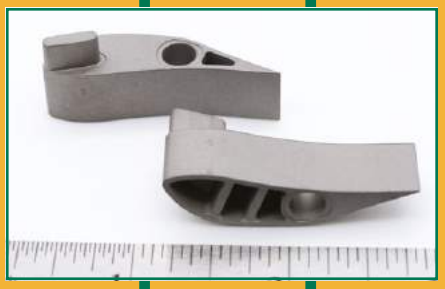

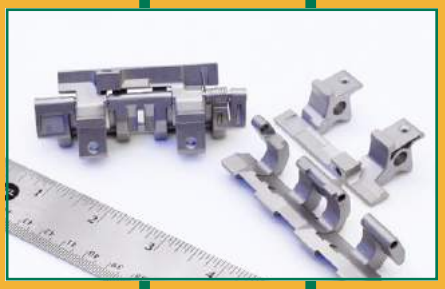

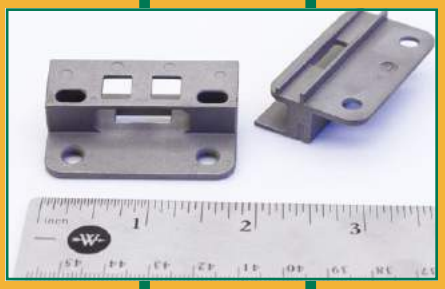

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JPMA Awards 2020: A showcase of innovation in PM for new and existing applications

The winners of this year's Japan Powder Metallurgy Association (JPMA) Awards highlighted the ongoing developments being made by Japan's PM industry, as it strives to gain further applications for Powder Metallurgy. The winners included innovations in component development and processing technology, showcasing the design and commercial benefits to using Powder Metallurgy as a manufacturing technique for mass production in numerous end-user categories.

Development awards: New design

Sintering of bearings for automotive LED headlight cooling fans

Porite Corporation received this award for its sintered bearings for automotive LED headlight fans. In recent years, LED headlights have been required to have higher heat dissipation due to an increase in the amount of light emitted and miniaturisation and cooling fans are being installed. The bearing in question has the required characteristics of quietness, long life, low temperature (-40°C) startability, wide practical temperature (-40°C to 120°C) range and prevention of a brightness decrease due to outgassing. Therefore, fluid bearings and ball bearings are often used, even though they are expensive.

In this innovation (Fig. 1), the company has ensured slidability and startability by optimising the sliding parts and reducing shaft loss by taking advantage of the characteristics of the centre-free bearing. Noise levels have been improved by ensuring co-axiality with an inner diameter tolerance width of 4 μm, a difficult requirement for bearings with an aspect ratio of more than five, and reducing the clearance with the shaft. The inner diameter chamfered shape makes it possible to extend the life of the bearing by giving the end face and the groove shape on the outer circumference a function in retaining the

Fig. 1 Bearings for automotive LED headlight cooling fans developed by Porite Corporation (Courtesy JPMA)

Fig. 2 Using Powder Metallurgy, Fine Sinter Co., Ltd. could reduce the cost of this parking lock part (Courtesy JPMA)

impregnated oil that leaks due to thermal expansion during operation.

In relation to material selection, a copper-coated iron powder is used. By achieving both a high oil content and low air permeability, the oil film strength of the bearing surface is secured and noise levels and wear resistance are improved. The company has also developed an impregnating oil with a small amount of evaporation in a high temperature environment by selecting ingredients that have little change in viscosity index from low to high temperature and that take into consideration the adverse effects of outgassing (decrease in brightness and chemical attack).

As a result, characteristics superior to ball bearings have been achieved and the product has been adopted as bearings for fan motors in the LED headlight bulb cooling system. This development has contributed to the expansion of the sintered oil-impregnated bearing market.

Optimising Powder Metallurgy process to mould a curved groove in a parking lock part

The second award in this category went to Fine Sinter Co. Ltd for a cost-reduction exercise to mould the curved groove of a parking lock part. The product (Fig. 2), was a pole support part used for the parking lock mechanism in an automatic transmission. In the trial evaluation process of this development, a groove shape with a changing curvature was required to prevent deformation of the mating part (cam). This groove and the bolt hole, which is used to assemble and fix the product, are in an orthogonal relationship. In the normal design, the part is net-shaped and the rest is machined, but the product with a net-shaped groove has been formed without machining by using undercut compaction.

"This development has contributed to the expansion of the sintered oil-impregnated bearing market..."

Undercut compaction requires control of the compression ratio for the undercut portion, such as using CNC for tool control, therefore the mechanism becomes complex. However, by using the general withdrawal mechanism (with one upper and two lower stages in the mould configuration), the position of the punch, used to form the undercut portion, is synchronised with the die by the operation of the upper punch. The stable net shape has thus been made successfully and inexpensively.

Local tool lubrication with oil plays an important role in this undercut compaction. The undercut portion forming punch receives a high stress in an outer peripheral direction during compaction. The structure of die inner diameter is designed to endure this stress. The tool lubrication is used to maintain the stable sliding of the punch and also to prevent the tool galling.

Sintered component used in a motorcycle transmission

The final award in this category was made to Diamet Corporation for a cam used for the shift mechanism of a motorcycle transmission (Fig. 3). When the power from the shift lever is transmitted to the shift fork, the pins of this part experience both high bending load and impact load. Therefore, the sinter forging method has long been adopted for this part, even though it is expensive. In recent years, the adoption of the investment casting method or replacement with the steel pin method has been expanding. The purpose of this development was, therefore, to enable the application of the press and sinter method to this part.

The density of the pins was increased to improve strength and the pin shape was reviewed to relieve a stress concentration. The raw metal powder, lubricant and filling method were all optimised to achieve a sintered density of 7.4g/cm^3, applying high pressure compaction and high temperature sintering.

Also, machining was eliminated by suppressing the variation of pin height to less than 0.1 mm. Although the risk of cracks, caused by mould distortion, remained, part quality was guaranteed by 100% inspection using a load test of the pins.

As a result, equivalent strength to the sinter forged part was achieved, with a cost reduction of 40%.

Fig. 3 This cam, developed by Diamet Corporation, is used for the shift mechanism of a motorcycle transmission (Courtesy JPMA)

Development awards: Process development

Soft Magnetic Composites for reactors in HEV that secures magnetic flux density and reduces iron loss

The remaining development award was in the Process Development category. This went to Sumitomo Electric industries for a compaction method that prevents damage to the surface insulating coating of Soft Magnetic Composites (SMCs) (Fig. 4). When the compacted product is ejected from the tool, friction between the tool and the product can damage the insulating coating, inducing the iron powder particles to conduct with each other and causing an overcurrent on the surface of SMC and increasing iron loss. Preventing eddy current loss, by generating iron oxide in the conductive part using a laser processing technique, can counter the iron loss. However, the use of laser processing is a costly option.

In order to solve the issue of damage to the insulation coating for one piece of the product, due to the outer peripheral surface being entirely formed by the die, a simultaneous compacting method was

Fig. 4 Sumitomo Electric Industries, Ltd. developed a compaction method that prevents damage to the surface insulating coating of Soft Magnetic Composites (Courtesy JPMA)

Fig. 5 Porite Corporation developed these bearings for refrigerator evaporator and condenser cooling fans (Courtesy JPMA)

developed. Here, the two pieces are in a die with a floating core rod acting as a tool between the two pieces, moving along with the two compacted products when they are ejected. As a result, the additional laser processing was eliminated and a cost reduction was realised.

In relation to the development of materials, the density of products was increased by optimising the particle size of the raw material powder and compaction conditions. In the annealing process, the stress of the product was relieved by optimising the conditions, which resulted in a reduction of iron loss by 25%.

It is expected that the production volume for this type of part will increase due to the expansion of the share of HEV and EV in the future and this development is anticipated to be very advantageous.

Award for effort

Development of bearings for refrigerator evaporator and condenser cooling fans

Two effort prizes have been awarded, the first was made to Porite Corporation for the development of bearings for refrigerator evaporator and condenser cooling fans (Fig. 5). Normally, the evaporator fan is used in an environment of -30°C and the condenser fan is used in an environment of + 60°C. Previously, each of these has used different optimised types of bearing.

In this new development, a long life has been achieved by selecting the optimum material and setting it to a high oil content. In addition, by developing a new silicone-based lubricating oil, the requirements in the low temperature environment (quietness, corrosion resistance and low friction characteristics) and those in the high temperature environment (wear resistance, low friction characteristics) were satisfied.

By unifying the bearings for refrigerator evaporator and condenser fans, cost competitiveness and shortening of lead time due to economies of scale were gained. In addition, as customer benefits, simplified ordering and inventory management and prevention of mixing up of different types in assembly lines are anticipated.

Development of lower cost Carbon/Carbon composite metalised carbon contact strip

Finally, Fine Sinter Co. Ltd. also received an effort prize for the development of lower-cost Carbon/

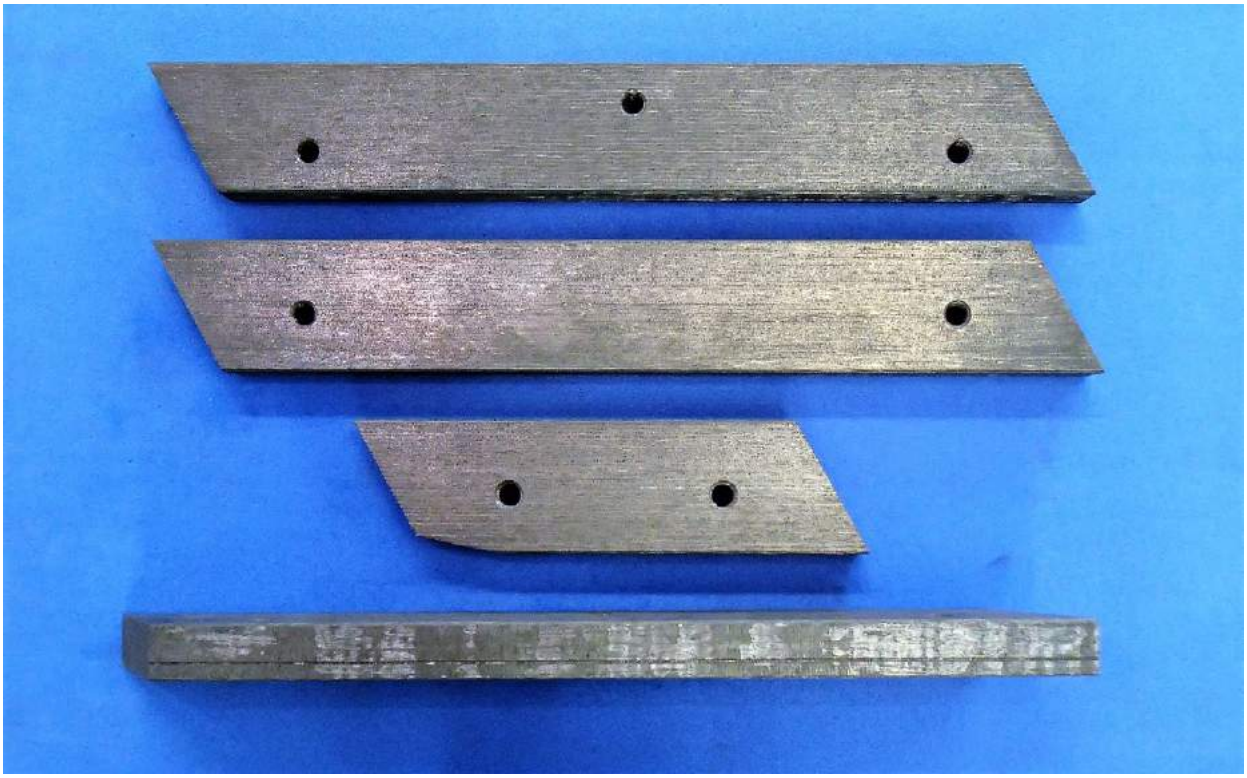

Fig. 6 Fine Sinter Co., Ltd developed this lower-cost C/C composite metallised carbon contact strip attached to the uppermost part of the pantograph on a railway vehicle (Courtesy JPMA)

Carbon (C/C) composite metallised carbon contact strip. This contact strip (Fig. 6) is attached to the uppermost part of the pantograph on top of a railway vehicle to collect electric current by contacting trolley wire to supply electricity to the railway vehicles.

Contact strips can be classified roughly into two types: metallic and carbon (copper and carbon composite). The carbon type is further classified into copper-impregnated types, copper-carbon mixed sintered types and copper-infiltrated C/C composite types. This development focused on the copper-infiltrated C/C composite types, characterised by light weight, high strength, low wear and low trolley wire aggression.

The issue to be addressed was the cost of C/C composite. This development aimed to reduce the amount of expensive carbon fibre. In order to reduce the amount of carbon fibres but ensure strength, it is necessary to increase the amount of binder. At first, in order to simplify the manufacturing process, the carbon base material was made by the preformed yarn method, where carbon fibres and binder are bundled together to form sheets. However, when the amount of carbon fibres is reduced and the amount of binder is increased, the copper infiltration route becomes narrower and sufficient copper infiltration becomes difficult.

This leads to difficulty in obtaining the required electrical characteristics. Therefore, the composition of the Cu-Ti infiltration material was modified and the infiltration conditions optimised (two step temperature setting). As a result, the developed contact strip ensured the required electrical conductivity and an improvement in strength by about 20%. The wear rate was reduced by 20% and the wear limit was increased by 10%. Cost performance was improved by 35% compared with conventional products.

"The wear rate was reduced by 20% and the wear limit was increased by 10%. Cost performance was improved by 35% compared with conventional products..."

Contact

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Understanding how the surface area of metal powders influences Additive Manufacturing

The surface area of particles in metal powders is affected by particle size, shape, roughness and porosity. Even spherical gas atomised metal powders exhibit surface areas much higher than suggested by their size. In this article, Dave van der Wiel, Director of Technology Development at NSL Analytical Services, discusses the topic and explains why the knowledge and use of powder surface area is a critical parameter in the metal Additive Manufacturing process.

Particle morphology affects powder-based Additive Manufacturing in several ways. During powder handling, for example, the surface area of a powder strongly impacts the uptake of ambient moisture and subsequent oxidation. On the build plate, particle morphology affects the flowability, spreadability and packing of powder. Particle surface area also affects interactions between metals and binders, and strongly impacts sintering kinetics. High-temperature reactions with oxygen and nitrogen on powder surfaces during sintering and reuse are also influenced by particle morphology.

To visualise the significance of the surface area of a metal powder, consider a 30 µm iron powder with a specific surface area of 0.63 m^2/g. One hundred grams of this powder would have a surface area of 63 m^2 – nearly the area of a racquetball court. Smooth iron spheres of this size provide only 4% as much surface area, about 2.6 m^2. Fig. 1 shows where particle surface area fits uniquely into a comprehensive powder characterisation matrix, as a particle-scale morphological property (particle shape and surface texture).

Contributors to surface area in particles

For low-porosity materials, the total external (accessible) surface area of a particle is primarily a function of particle size. The 'geometric surface

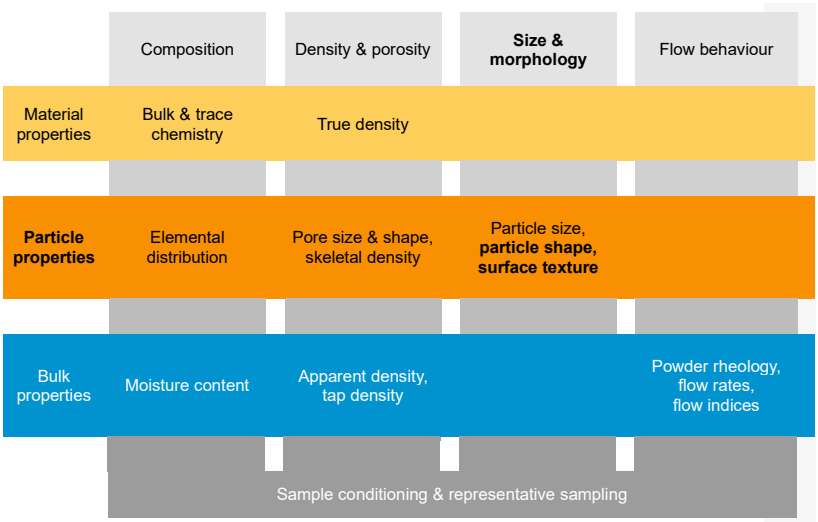

Fig. 1 Particle morphology properties associated with specific surface area

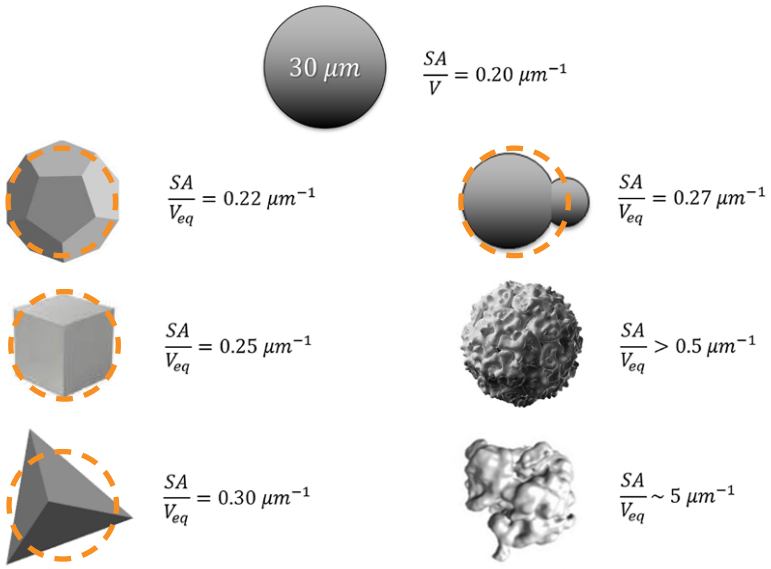

Fig. 2 Impact of particle morphology on surface area; the lower right object represents a water atomised iron particle with a surface area of 0.63 m²/g

area' of a particle can be calculated from its median diameter, assuming perfect sphericity. A 30 μm sphere has a geometric surface area of 2,803 μm² and a surface area-to-volume ratio of 3/r, or 0.20 μm⁻¹.

The surface area of a powder can therefore be roughly approximated from a particle size distribution measurement. However, as shown in Fig. 2, for a given equivalent diameter, the actual surface area of real particles is strongly affected by particle shape, agglomerates, porosity and texture. For the previously mentioned 30 μm iron powder with a specific surface area of 0.63 m²/g, the surface area-to-volume ratio is 4.9 μm⁻¹ – twenty-five times greater than the smooth sphere case.

Particle morphology parameters & measurements

ISO 9276-6 provides a comprehensive list of particle shape parameters, both qualitative and quantitative [2]. These and similar morphological parameters can be grouped according to their type and scale, as shown in Table 1.

Macroshape parameters such as particle elongation are assumed to be three-dimensional and their impact on surface area is estimated based on various types of equivalent dimensions or volumes. Mesoshape parameters such as particle circularity are based on two-dimension 'shadows' of particle images (or size modes) and are estimated using equivalent areas or perimeters, for example. Surface texture is represented by parameters such as roughness factors, and (when possible) is calculated using various geometric calculations.

The techniques used to analyse for these parameters include optical image analysis, microscopy, tomography and light scattering. Some of these techniques have the advantage of simultaneously providing particle size data. The primary disadvantage of these methods is that they are indirect (and two-dimensional) estimates of three-dimensional morphologies, and either only sample 10s to 100s of particles at a time or have a limited meso/micro-scale resolution. In contrast, gas adsorption techniques provide true three-dimensional physical measurements of surface area on 10^5 to 10^7 particles.

Although particle surface area can be estimated from size and/or shape parameters, this approach does not account for microstructural features. It has been shown, for example, that even spherical gas atomised metal powders exhibit measured specific surface areas 1.8 x higher than those estimated based on particle size data [1].

Parameter scale	Particle		Surface/texture	
	"Macroshape"	"Mesoshape"	Meso	Macro to micro
Parameters	Sphericity, elongation	Circularity, angularity	Roughness factor	Surface area
Nature	3D	2D	2D	3D
Basis	Equivalent dimensions or volume	Equivalent area or perimeter Fractal analysis	Geometric or fractal analysis	Physical measurement
Techniques	Digital imaging, microscopy, tomography, laser scattering			Gas adsorption (BET)
Particles analysed	> 10 to > 100 for static microscopy > 1,000,000 for dynamic digital imaging			100,000s to 10,000,000s

Table 1 Particle morphology types, scales and measurement

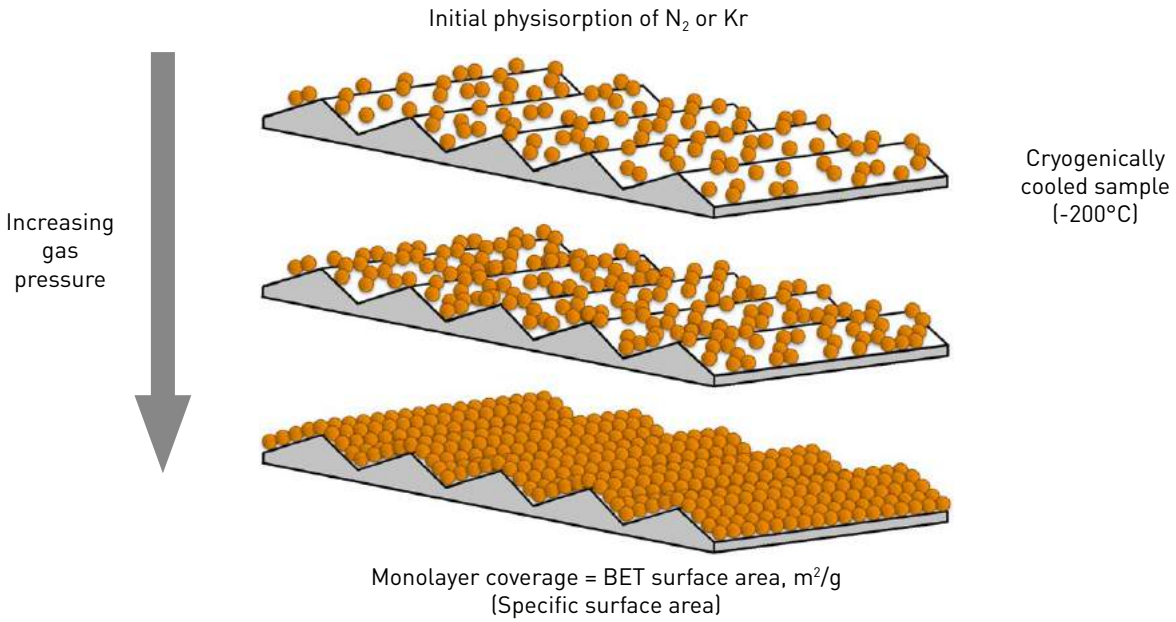

Fig. 3 Measurement of specific surface area by gas adsorption

BET surface area of metal particles

The same van der Waals forces that are responsible for particle-to-particle adhesion in < 100 µm powders also lead to the adsorption of gases on solid surfaces. This phenomenon is used to quantitatively measure the surface area of solid surfaces using the well-known BET method [3, 4].

This method involves cooling a sample to cryogenic temperatures, followed by stepwise introduction of an adsorbate gas (Fig. 3). Liquid nitrogen (77K) is used as the cryogenic medium for convenience. The equilibrium pressure after each successive gas dose generates an adsorption isotherm until monolayer coverage is reached. A model is applied to the adsorption data to provide the specific surface area, expressed in m^2/g (or m^2/kg).

For materials with surface areas of less than about 1 m^2/g, it is necessary to use krypton gas as the adsorbent instead of the more common adsorbate nitrogen. The lower saturation vapour pressure of liquid Kr at 77K (350 Pa compared to 101 kPa for N_2) reduces the amount of dead volume gas by a factor of about 300, thus increasing the magnitude (and therefore the resolution) of the pressure differentials used for the BET method. Krypton is therefore recommended for low surface area materials by IUPAC [5], ISO [6] and ASTM [7].

Relevant BET gas adsorption test standards include ISO 9277 [6], ASTM B922 [8] for metal powders and ASTM D4780 [7]. Although the latter standard applies to ceramics, it is specific to krypton adsorption for low surface area materials. Luk provides a review of the measurement and calculation of the surface area of metal powders, including a thorough review of the BET gas adsorption method [9].

Badalyan & Pendleton conducted a rigorous analysis of the propagation of uncertainty in N_2 BET measurements, estimating a relative combined uncertainty of ±0.63% [10]. More recently, the ASTM B09 committee conducted an interlaboratory study for test method B922, which included both N_2 and Kr BET measurements from five laboratories [11]. The materials used in this study included stainless steel and tungsten powders with surface area values from 0.140 to 0.546 m^2/g. The relative standard deviation values for repeatability in this study range from 1.6–11.4%.

Unsurprisingly, all these studies report diminished precision as surface area value decreases. The BAM reference procedure for gas adsorption reports an uncertainty of ± 10% for a 0.1 m^2/g material [12]. However, to the author's knowledge, no such studies have been conducted on metal powders exclusively using krypton gas as a sole adsorbate.

Micromeretics provides approximations of the maximum uncertainty for a range of total sample surface areas using either N_2 or Kr gas (Table 2) [13]. As can be seen, only Kr provides acceptable uncertainties for the measurement of low surface area materials.

Examples of variations in surface area due to metal particle morphology

Table 3 lists some properties of three similarly-sized commercial iron powders produced by Höganäs AB. The different production methods used for these powders are known to result in substantially different particle morphologies.

The particle size distribution for these powders is quite similar, ranging from about 20 µm to 180 µm, with 18% to 23% less than 45 µm,

Total sample area (m^2)	Maximum uncertainty	
	N_2	Kr
10	2.4 to 6.7%	0.20%
5	4.7 to 13%	0.31%
2	12 to 34%	0.77%
1	24 to 67%	1.5%
0.5		3.1%
0.2		7.7%

Table 2 Maximum uncertainty in BET surface area for N_2 and Kr adsorption (Micromeretics [13])

resulting in median diameters that vary by only about 2%. The porosity and shape differences of these powders produce about 4–5% variation in their densities. Yet the measured specific surface areas differ by 40%, providing clear quantification of the morphological differences between these powders.

The correlation of powder-specific surface area and particle morphology has been described by many authors, including Unal *et al.*, who studied the impacts of gas atomising conditions on ca. 35 µm aluminium powders using both BET surface area and electron microscopy (Table 4) [14, 15]. The authors demonstrated that specific surface area values below 200 m^2/kg corresponded to spherical particles, 255 to 306 m^2/kg to globular or elongated particles and 302 to 316 m^2/kg to angular particles. Obviously, the BET surface area data has the advantage of being quantitative, more representative and easier to gather.

Application to Additive Manufacturing

Water atomised powders commonly used in conventional Powder Metallurgy processes can have irregularly shaped particles with relatively high surface area. Air- and inert gas atomised powders were initially developed for oxygen-sensitive materials like aluminium and titanium. The high sphericity of gas atomised powders improves handling for use in Additive Manufacturing, but provides much lower surface area (Table 5 [16]). The larger particle size ranges used in AM processes also provide less surface area compared to conventional PM processes.

	Sponge iron		Atomised iron	
	NC100.24	SC100.26	ASC100.29	Variation
d50 (µm)	87	85	84	**±1.5%**
Apparent density (g/cm^3)	2.45	2.7	2.8	±4.7%
Tap density (g/cm^3)	3.2	3.5	3.5	±4.2%
Surface area (m^2/kg)	60	40	20	**±41%**

Table 3 Variation in surface area of three similarly sized iron powders

Sintering of particles is driven by the excess free surface energy associated with their relative high surface area, and many studies have shown the improvements in densification resulting from the addition of higher surface area metals powders to lower surface area spherical powders (Table 6 [17])

Depending on the material and AM process used, powder surface area may be optimal at either higher or lower levels.

Lower surface area:

- Decreases the reactivity of metals such as titanium, aluminium, etc.
- Decreases sensitivity of product powders towards ambient moisture

While higher surface area:

- Promotes sintering and densification – potentially offsetting lower green densities
- Improves interactions between metals and binders.

Other considerations related to powder surface area include the fact that the focus of cost reductions in many AM processes is shifting from equipment to raw materials, and inert gas atomised powders can be ten times more expensive than their water atomised analogs. In addition, highly spherical powders may not be necessary in all powder bed processes, and powder recycling can drive toward less-reactive morphologies.

These factors, along with the use of H_2 sintering to remove oxygen, have increased interest in the use of water atomised powders in some AM processes [18–21]. Similarly, the use of non-spherical powders from Hydride-Dehydride (HDH) processes is seeing increased application to AM [22, 23].

Zhou studied the densification of stainless steel 420 specimens produced by binder jet Additive Manufacturing (BJT) using 30 µm water and gas atomised powders [24, 25]. This work employed fractal analysis of electron micrographs to describe the particle morphology; for a description of fractal dimension, see Klobes 2006 [4].

As applied by Zhou to micrographs at 1000 x magnification, the fractal

Powder type	Atomisation gas	Median particle diameter (µm)		Surface area (m^2/kg)	SEM morphology
Al	21% O_2	42.1	Avrg 33.6	**316**	**Angular**
	12% O_2	25.0		**302**	
	6% O_2	33.1	Avrg 33.9	**306**	**Elongated**
	N_2 – 5% O_2	34.7		**290**	
	3% O_2	33.1	Avrg 34.6	**287**	**Globular**
	N_2 - 3% O_2	36.0		**255**	
	2% O_2	31.9	Avrg 34.3	**187**	**Spherical**
	1% O_2	34.8		**151**	
	N_2 – 0.5% O_2	35.8		**133**	
	N_2	34.5		**135**	
AlCuMgSi	N_2	31.9	Avrg 33.7	**139**	**Spherical**
	Ar	31.9		**137**	
	Ar	37.1		**119**	

Table 4 Correlation between particle morphology and surface area for gas atomised aluminium powders [14,15]

dimension would be included as a 'mesoshape' parameter in Table 1. One would therefore expect fractal dimension to vary in proportion to surface area, but with considerably less sensitivity since it neglects microtextural effects; in fact, Jiqiao & Baiyun showed that BET surface area variations on tungsten powders were about 10 x greater than fractal dimension [26]. Table 7 shows the sintered porosity and densification of two representative specimens which employed the two powder types, with each powder's fractal dimension indicated [24, 25]. As can be seen, the less uniform water atomised powder produced lower porosity and higher densification at a given sintering condition. Fig. 4 (adapted from Zhou) demonstrates both increased kinetics and extent of sintering with the higher surface area powder.

Similarly, Hoeges *et al.* studied Laser Beam Powder Bed Fusion (PBF-LB) of water and gas atomised 316L powders [27], and Nomura *et al.* have reported on the mechanical performance of cobalt alloy specimens produced by PBF of water and gas atomised powders [28]. In these cases too, specimens produced from higher surface area water atomised

Particle size, d50	17-4PH Powder surface area	
	Gas atomised	Water atomised
6.5 – 8.0 µm	0.31 m^2/g	0.36 m^2/g
10 – 11 µm	0.23 m^2/g	0.34 m^2/g
19 – 20 µm	0.15 m^2/g	0.22 m^2/g

+50%

Table 5 Comparison of surface areas of gas and water atomised powders [16]

Powder fractions		Sintered specimens	
Water atomised (203 m^2/kg)	Gas atomised (89 m^2/kg)	Density (g/cm^3)	Porosity (%)
0%	100%	7.36	7.94
25%	75%	7.43	7.12
50%	50%	7.56	5.44
75%	25%	7.60	5.00
100%	0%	7.61	4.87

Table 6 Density and porosity of sintered 316L as a function of powder surface area [17]

Powder (30-µm)		Sintered specimen	
Type	Fractal dimension	Porosity	Densification
Water atomised	1.70	3.9%	90%
Gas atomised	1.03	9.1%	70%

Table 7 Impact of particle morphology on powder-bed printed stainless steel 420 [24, 25]

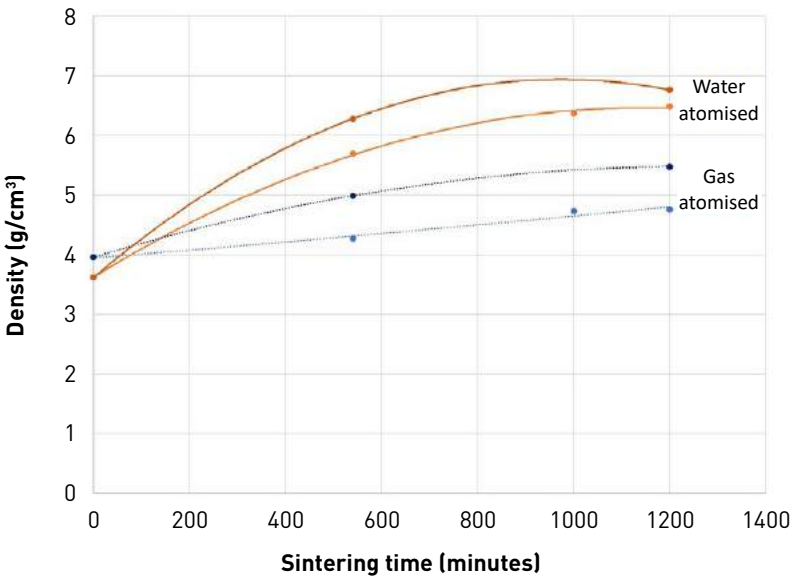

Fig. 4 Kinetics and extent of powder-bed sintering of two stainless steel 420 powders (adapted from [24,25])

powders were capable of producing physical and/or mechanical properties that were comparable or better than low surface area gas atomised powders. The authors in both studies indicated that the improved sintering of the high surface area powders offsets disadvantages of lower flowability and/or green densities.

Summary

Metal particle surface area measurements by krypton gas adsorption provide direct measurement of multi-scale, three-dimensional particle morphology on samples comprising millions of particles. As such, they represent a unique facet of powder characterisation that is not represented by direct estimates of two-dimensional particle representations.

The dramatic impact of particle surface area on sintering processes is well-known and has been shown to offset challenges in powder handling where non-spherical powders are employed in AM processes. Thus, with raw material costs and powder reuse an increasing concern, the knowledge and use of powder surface area has re-emerged as a critical parameter in metal Additive Manufacturing.

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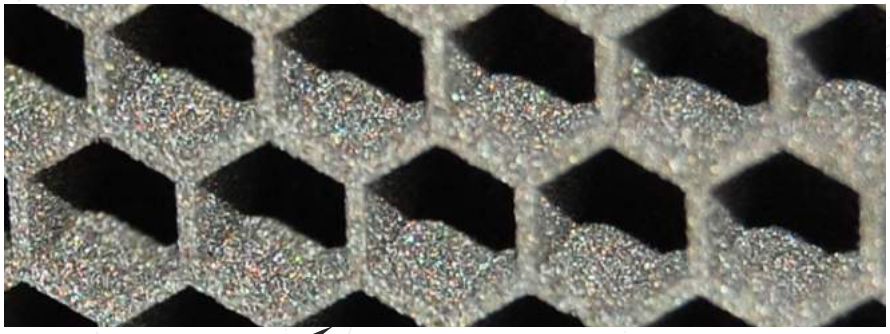

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Euro PM2020: PM functional materials in energy management and magnetic applications

Technical sessions within the programme of the successful Euro PM2020 Virtual Congress, organised by the European Powder Metallurgy Association (EPMA) from October 5–7, 2020, considered the powder metallurgical processing of functional materials in two application categories, energy management and magnetic applications. Dr David Whittaker provides a summary of these presentations, highlighting the key topics presented in the papers.

Resin bonded magnetocaloric plates with a thickness of 0.3 mm produced from gas atomised powder

The first example of an energy management application was presented by Nerea Burgos, B L Checa and J M Martin (CEIT- Basque Research and Technology Alliance and University of Navarra, Spain), M Ipatov and J Gonzalez (University of the Basque Country, Spain), who considered the manufacture of resin-bonded magnetocaloric plates with a thickness of 0.3 mm from gas atomised powder [1].

The authors state that magneto-caloric refrigeration has the potential to be up to 20% more efficient, in terms of energy consumption, than the conventional technology based on the compression/expansion cycle of a refrigerant fluid. It was also stated that its use will contribute to a reduction in the use of fluorinated gases, which have significant greenhouse effects.

$LaFe_{13-x}Si_x$ alloys have proven to be the most promising material for commercial applications due to their significant magnetocaloric effect, low thermo-magnetic hysteresis, high magnetisation and high thermal conductivity. Furthermore, they are relatively cheap and non-toxic. Curie temperature can be varied between -80 and 55°C, while keeping a high magnetocaloric effect, by controlling the degree of hydrogenation.

However, $LaFe_{13-x}Si_xH_y$ alloys that are partially hydrogenated are not chemically stable when used at temperatures close to their Curie

Fig. 1 Euro PM2020 took place online due to the ongoing coronavirus pandemic

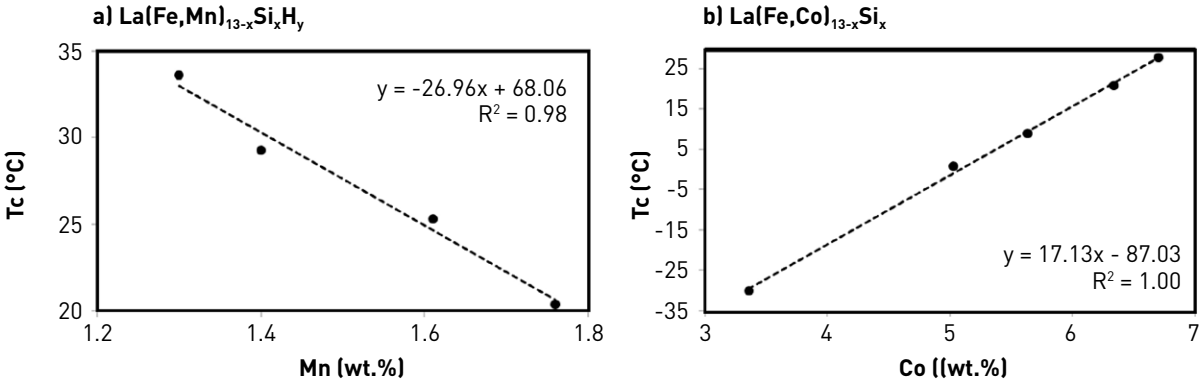


Fig. 2 Correlation between Tc and Mn or Co content [1]

temperature. In order to be stable, alloys must be fully hydrogenated. The value of T_c can be adjusted into the range of interest for practical applications by changing the concentration of Mn. Another possibility is the use of non-hydrogenated quaternary alloys $La(Fe,Co)_{13-x}Si_x$. In this case, the Curie temperature is tuned through small additions of Co, although the magnetocaloric effect decreases at the same time.

One of the most important requirements in the design of a magnetocaloric block is that the contact surface area with the heat transfer fluid (HTF) must be maximised to improve the heat exchange between both. Several studies have shown that the most efficient design is one in which the liquid layer is approximately 0.1-0.2 mm in thickness and flows between plates of magnetocaloric material of 0.3-1 mm in thickness.

The first objective of the reported work was the production of La-Fe-Si alloys by gas atomisation with low oxygen content and the desired Curie temperature in the range of 0 – 30°C. This required careful control of the composition, which is challenging because lanthanum reacts with crucible materials during melting. The second objective was to manufacture plates from these powders with a high volume fraction of magnetocaloric phase, comparable to the values previously reported (between 60 and 73%), no distortion and a thickness of ~0.3 mm. The selected manufacturing technology was compression moulding.

The alloys $La(Fe,Co)_{13-x}Si_x$ and $La(Fe,Mn)_{13-x}Si_x$ were produced by gas atomisation with Ar using a convergent-divergent close-coupled atomiser. Before atomisation, the chamber was evacuated and purged with Ar to minimise oxidation. Two prealloyed materials (Fe-La-Co-Si and Fe-La-Mn-Si) were purchased. The appropriate alloy was melted in an induction furnace under a high-purity Ar atmosphere. The necessary raw materials in elemental form were added to change the composition of the alloys. Sacrificial lanthanum was added to compensate for the losses during melting.

Since the powders obtained by atomisation mainly consisted of α-Fe and FeLaSi, they were heat treated at high temperature to form the magnetocaloric phase $La(Fe(Co/Mn),Si)_{13}$. In the case of Mn-containing alloys, they were subsequently hydrogenated to form $La(Fe,Mn)_{13-x}Si_xH_y$.

In order to form plates by compression moulding, the powder was granulated with a one-component epoxy resin. Mixing was carried out in wet media. First, the epoxy resin was dissolved in acetone (4 g of resin per 1 ml of acetone), next the powder was added and, finally, the solvent was evaporated. The plates were produced by uniaxial compaction in a press. Subsequently, the resin was cured for 10 h at 130°C under air.

Chemical formula	Reference	Composition (wt.%)						
		Fe	La	Si	Co	Mn	O	La:(Fe,Si,Co/Mn) ratio
$Fe_{11.28}La_{0.89}Si_{1.08}Co_{0.78}$	Co1	75.49	14.78	3.64	5.37		0.057	1:14.8
$Fe_{11.21}La_{0.91}Si_{1.05}Co_{0.84}$	Co2	74.66	15.01	3.51	5.92		0.048	1:14.5
$Fe_{11.11}La_{0.89}Si_{1.08}Co_{0.93}$	Co3	74.00	14.74	3.63	6.50		0.047	1:14.7
$Fe_{11.47}La_{0.93}Si_{1.27}Mn_{0.34}$	Mn1	76.64	15.47	4.26		2.23	0.055	1:14.0
$Fe_{11.53}La_{0.97}Si_{1.22}Mn_{0.29}$	Mn2	76.93	16.11	4.10		1.89	0.070	1:13.4
$Fe_{11.63}La0_{.88}Si_{1.28}Mn_{0.23}$	Mn3	78.65	14.63	4.36		1.55	0.061	1:15.1

Table 1 Composition of the powders (wt.%) and stoichiometric ratio La:(Fe,Si,Co/Mn) [1]

Based on data from four $La(Fe,Mn)_{13-x}Si_xH_y$ powders, a linear correlation was established between T_c and Mn content, as shown in Fig. 2a. The Curie temperature increased by 27°C when the Mn concentration was reduced by 1 wt.% For $La(Fe,Co)_{13-x}Si_x$ alloys, the choice of composition was based on data from the literature, which defined a correlation between T_c and Co content in alloys with different concentrations of Si. These data showed that the maximum entropy change under isothermal conditions (ΔSm) for an applied field of 2 T rises when the Si content is reduced. Therefore, alloys with 3.69 wt.% of Si were selected. For this silicon level, it was determined that the Curie temperature rises by 17.1°C when the Co concentration increases by 1 wt.% (Fig. 2b). Thus, alloys with the desired Curie temperature can be selected in both families by using these ratios to adjust the Mn or Co concentration.

Table 1 displays the chemical composition of the powders produced. The last column shows the stoichiometric ratio La:(Fe,Si,Co/Mn), which is lower than the ideal value of 1:13 in all cases, meaning that the materials were slightly depleted in lanthanum. As a result, some excess of free α-Fe phase would be observed after annealing the powders to obtain the magnetocaloric phase. Table 2 shows the main descriptors of the particle size distributions of the as-atomised powders. The powders were very fine, e.g. more than 90% of the powder is < 100 µm. This is important, since the magnetocaloric plates should have a thickness as close as possible to 300 µm.

As expected for inert gas atomised powders, the particles were spherical. The microstructures consisted of two main phases. According to the Energy Dispersive Spectroscopy (EDS) analysis, the darkest phase contained approximately 90 wt.% of Fe, so was likely to be α-Fe, with some minor elements in solution. The brightest phase contained high amounts of La, Fe, and Si, so was likely to be FeLaSi. Fig. 3 shows the XRD patterns of the six alloys. The patterns confirmed the main phases as α-Fe and FeLaSi.

In relation to powder annealing, the optimum temperature is usually close to the solidus temperature of the alloy. DSC experiments were conducted to determine this. Fig. 4 shows the thermal transitions occurring in the alloys when they were heated. The first endothermic events, revealing the formation of liquid phases, occurred between 1000 and 1150°C (P1 and P2), but the amount

Property	Reference					
	Co1	Co2	Co3	Mn1	Mn2	Mn3
D10 (µm)	8.1	8.8	9.2	8.3	7.3	8.7
D50 (µm)	24.7	30.4	29.8	28.5	22.0	28.4
D90 (µm)	79.5	97.5	94.5	95.0	50.6	91.3

Table 2 10th percent percentile (D10), median particle size (D50), and 90th percent percentile (D90) of the particle size distributions [1]

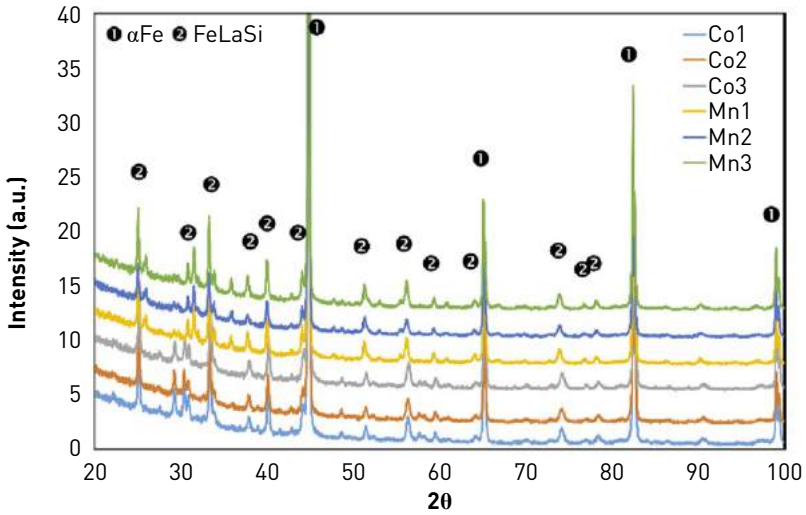


Fig. 3 XRD patterns of as-atomised powders [1]

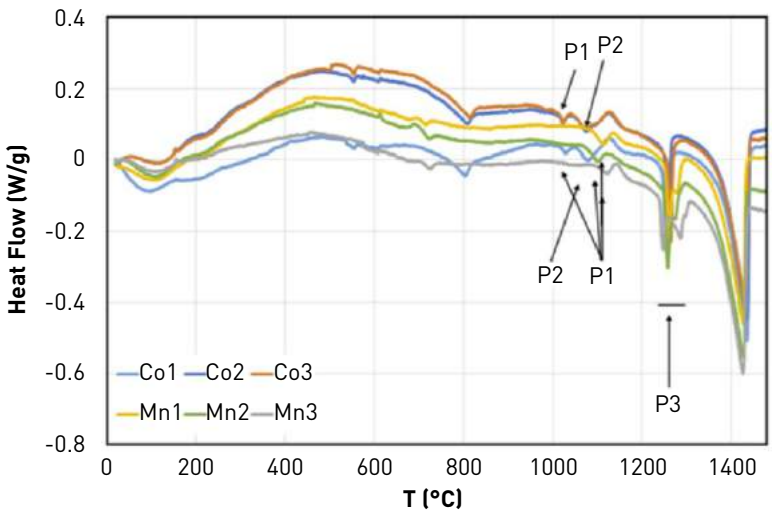


Fig. 4 DSC traces of as-atomised powders [1]

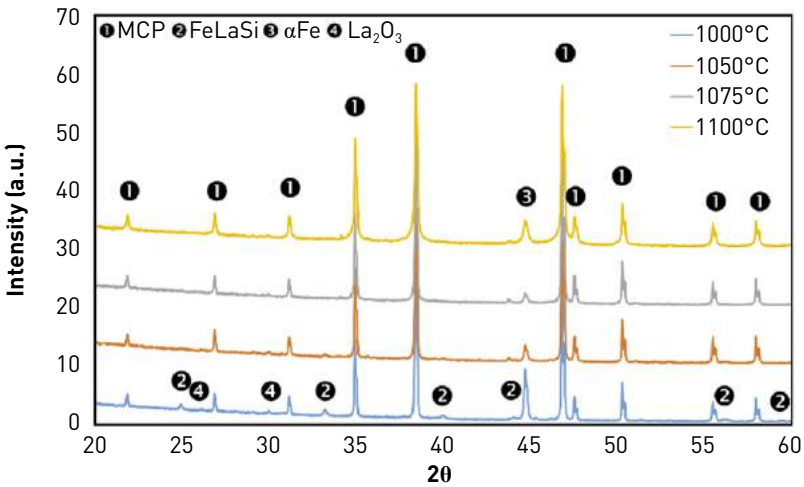


Fig. 5 XRD patterns of composition Mn2 annealed at different temperatures [1]

Reference	Phases (wt.%)		
	MCP	α-Fe	La_2O_3
Co1	91.00	8.64	0.27
Co2	92.83	6.80	0.37
Co3	90.43	8.01	0.18
Mn1	93.23	6.42	0.35
Mn2	95.87	3.87	0.25
Mn3	87.79	11.88	0.33

Table 3 Weight fraction (wt.%) of the constituent phases in the powders annealed at 1075°C [1]

of liquid formed seemed quite small. A more significant amount of liquid formed at P3 (above 1200°C), which could be produced by the reaction of FeLaSi with the Fe-rich phase to form liquid and the magnetocaloric phase. Therefore, annealing was conducted at temperatures between 1000 and 1100°C for 4 h under Ar.

In all the alloys, the formation of a significant amount of magnetocaloric phase between 1000 and 1050°C was apparent. In the case of the Co-containing alloys, no further formation was observed between 1050 and 1100°C and the remaining α-Fe coarsened with temperature. In the case of the Mn-containing alloys, residual FeLaSi and α-Fe were still observed at 1075°C and did not appear to coarsen even at 1100°C. Sample Mn2 sintered more than the other samples, which is probably due to its lower particle size (see Table 2).

The evolution of the phases with the annealing temperature was also followed by XRD. In the diffraction patterns in Fig. 5, the peaks corresponding to the magnetocaloric phase (MCP), FeLaSi, α-Fe and La_2O_3 are marked with numbers from 1 to 4, respectively. This figure shows the evolution of the phases in alloy Mn2 with the annealing temperature. The characteristic peaks of FeLaSi at 33° and 40° disappear after annealing at temperatures above 1050°C. The characteristic peak of α-Fe at 45° decreases when the temperature is increased from 1000°C to 1075°C, but increases again when the heat treatment is carried out at 1100°C due to the destabilisation of the MCP. The weight fraction of magnetocaloric phase reaches a maximum when annealing is carried out at 1075°C and decreases when the temperature is increased to 1100°C. It was concluded that the annealing conditions to attain the maximum amount of magnetocaloric phase are 1075°C for 4 h under Ar. The maximum amount of magnetocaloric phase obtained after optimum annealing is reported in Table 3 for each composition. A very low oxygen content in the Ar atmosphere is critical for successful heat treatment of these alloys. Due to the high affinity of La for oxygen, a small amount of La_2O_3 was formed (Fig. 5). The formation of La oxide reduces the amount of metallic La available to form the magnetocaloric phase. Also, since the ratio La:(Fe,Si,Co/Mn) was lower than 1:13 (Table 1), all compositions exhibited a residual amount of α-Fe that cannot be eliminated.

Hydrogenation of the Mn-containing alloys was necessary in order to obtain Curie temperatures in the range of interest. This heat treatment was carried out under pure hydrogen at 300, 350, and 400°C for 1, 2, and 4 hours, seeking the total hydrogenation of the sample. When the phase is fully saturated at a given temperature, the Bragg angles reach a minimum value. The α-Fe peak does not shift during hydrogenation, since hydrogen does not dissolve significantly into the crystal lattice of this phase, so this peak was used to correct any instrumental error or sample displacement. Fig. 6 demonstrates that the peaks of the magnetocaloric phase shift to lower Bragg angles when the hydrogenation time is increased from 1 to 4 h at 300°C. As for the effect of annealing temperature, it is observed that the minimum Bragg angles are achieved at 350°C. At 400°C, the lattice parameter decreases again (i.e. the Bragg angle of the peaks increases), indicating that the sample is dehydrogenating.

Table 4 shows the Curie temperature of the alloys with Co after optimum annealing and its dependence on the hydrogenation conditions for the alloys with Mn.

In the case of the Mn-containing powders, the table shows that T_c is a maximum for samples hydrogenated at 350°C. These values are close to the expected ones. At 400°C, T_c decreases because of the dehydrogenation of the alloys. Thus, the measurements of Curie temperature agree with the XRD results.

The values obtained for T_c were in the interval of interest for practical applications (between 0 and 30°C). Consequently, the reported work has confirmed that it is possible to produce magnetocaloric powders of the La-Fe-Si family by gas atomisation with the desired Curie temperature by adjusting composition and annealing conditions.

The powders were sieved to use the fraction below 100 µm. For compression moulding, the variables that were optimised were the volume fraction of resin and the pressure and temperature of the compression moulding cycle. The reported study showed that the optimum volume fraction of resin in the mix is 20% v/v. Optimum moulding was achieved by pressing at room temperature and applying a pressure of 600 MPa. After curing, plates were obtained with a thickness of 0.3 mm, allowing channels of 0.15 mm for the HTF to flow, and a real volume fraction of MCP of up to 77%.

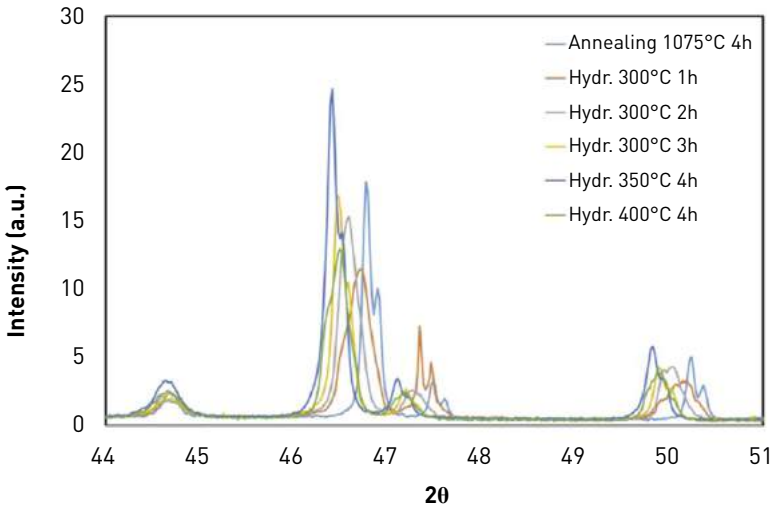


Fig. 6 XRD patterns of alloy Mn2 hydrogenated at the indicated temperatures and times [1]

Reference	As-annealed	Hyd. 300°C 4h	Hyd. 350°C 4h	Hyd. 400°C 4h
Co1	2.57			
Co2	10.43			
Co3	21.77			
Mn1		-2.28	3.13	-6.38
Mn2		-4.26	14.74	7.72
Mn3		7.45	19.04	10.61

Table 4 Curie temperature (°C) of the different alloys [1]

Porous transport layers made of niobium/steel composites for water electrolysis

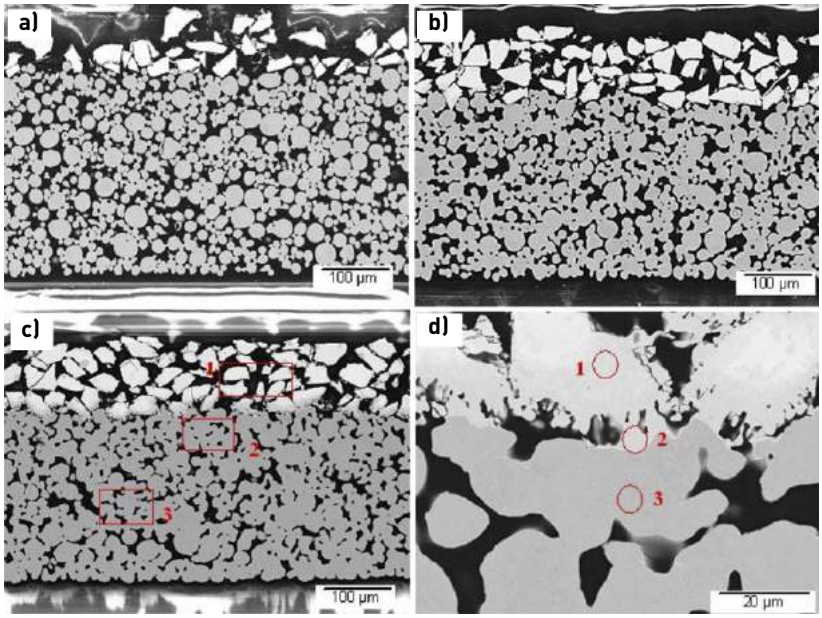
A second energy management study related to porous transport layers for water electrolysis made from niobium/steel composites and was reported by Natalia de Freitas Daudt (Federal University of Santa Maria, Brazil) and Franz Josef Hackermueller and Martin Bram (Forschungzentrum Juelich GmbH, Germany).

In future energy concepts, water splitting by polymer electrolyte membrane (PEM) electrolysis is said to be a key technology for converting regenerative energy from wind or sun into hydrogen [2].

A specific component of a PEM electrolyser that needs development is the porous transport layer (PTL) used on the anode side. PTLs control the transport of electrons, water and gas molecules, therefore they should have high and interconnected porosity as well as a homogeneous distribution of pores to enable gas to be expelled and water molecules to reach the catalytic active area. Also, PTLs require materials with sufficient corrosion resistance to withstand the high electrochemical over-potential, acid environment and presence of oxygen. In addition, high electrical conductivity and suitable mechanical strength to resist differential pressures up to 50 bar are prerequisites in the case of operating the system in high-pressure mode.

In the reported study, the potential of PTLs made of niobium/stainless steel composites was investigated. The use of stainless steel aims to lower material and manufacturing costs. However, as stainless steel has limited corrosion resistance in harsh environments such as in the anode of a PEM electrolyser, a niobium coating was proposed as a protective layer. A detailed investigation of manufacturing niobium/stainless steel (SS316L) composites by scalable powder metallurgical techniques, such as tape casting, screen printing and field assisted sintering/spark plasma sintering (FAST/SPS), was undertaken.

Spherical stainless steel 316L gas atomised powder (D10 = 11.7 µm, D50 = 18.6 µm, D90 = 29.0 µm) and acicular-shaped niobium powder



e)

Point	Nb (wt.%)	Fe (wt.%)	Cr (wt.%)	Ni (wt.%)	Mo (wt.%)	Mn (wt.%)
1	97	0.6	0.2	0.1	1.9	0.1
2	0.8	69.2	16.0	10.8	2.9	0.3
3	0.2	69.3	16.5	10.7	2.5	0.8

f)

Point	Nb (wt.%)	Fe (wt.%)	Cr (wt.%)	Ni (wt.%)	Mo (wt.%)	Mn (wt.%)
1	95.2	1.4	0.2	0.5	2.7	0.0
2	25.6	50.0	11.3	6.1	6.4	1.6
3	0.9	70.5	18.1	9.0	1.5	0.05

Fig. 7 SEM images of Nb/SS316L composites produced by printing Nb powders on green SS316L tapes and co-sintering at: (a) 1000°C, (b) 1100°C, (c,6d) 1150°C, (e) EDS of points indicated in (Fig c) and (f) EDS of points indicated in (Fig d) [2]

(D10 = 23.8 µm, D50 = 40.6 µm, D90 = 58.2 µm) were used as starting powders.

First, stainless steel (SS316L) substrates of 140 x 140 mm^2 and around 260 µm thickness were produced by tape casting using an automated tape casting line and an alcohol-based slurry developed in-house . For final shaping, the tapes were cut into 70 x 70 mm^2 samples, which were then heated to 500°C under argon flow to remove binder. Subsequent sintering took place at 1100°C under vacuum (10^{-3} Pa).

Nb/SS316L composites were produced by screen-printing a Nb layer on the surface of the tape cast substrates using a Nb slurry, based on a Terpineol and ethylcellulose solution. Screen-printing of the Nb layer was investigated on both green and pre-sintered SS316L tapes, pre-sintering being carried out at 1100°C. After printing, the samples were placed in an oven at 50°C for 3 h to remove solvents and then co-sintered in a vacuum furnace (10-3 Pa) at a temperature varying between 1000 and 1150°C for 3 h.

SEM images of the screen-printed Nb/SS316L composites are shown in Fig. 7. Due to weak sintering of Nb at 1000°C, Nb particles tend to partially flake off resulting in a slightly reduced layer thickness. With increasing sintering temperature, a higher interdiffusion of Nb, Fe, Cr, Mn and Ni atoms was found at the interface (Fig. 7) resulting in the formation of intermetallic compounds as confirmed by XRD. The formation of intermetallic compounds was mainly restricted to the interface region, but, nonetheless, these compounds can decrease the corrosion resistance and lead to embrittlement. Also, the difference in sintering activity and shrinkage between the niobium and SS316L layers resulted in convex sample bending at sintering temperatures above 1100°C.

In order to reduce this bending, Nb/SS316L composites were produced by screen-printing Nb powders on pre-sintered SS316L tapes followed by co-sintering at 1100 and 1150°C . The resulting microstructures and interdiffusion at the interface were found to be similar on green and pre-sintered tapes. Nevertheless, screen-printing and sintering of Nb powders on pre-sintered tapes reduced shrinkage and bending of the SS316L layer. Again, weak sintering of Nb at 1100°C led to partial flaking of Nb particles and therefore a reduced layer thickness. However, the bending of samples increased with sintering temperature (Fig. 8). Strategies such as controlled plastic deformation could be applied to decrease sample bending, and this will be part of the group's ongoing studies.

Field assisted sintering/spark plasma sintering of Nb/SS316L composites was also investigated. FAST/SPS aims to decrease the interdiffusion at the interface between niobium and the SS316L layer. At this stage of development, only dense layers were produced, since dense layers enabled the achievement of a more defined Nb/SS316L interface. FAST/SPS experiments were carried out in a lab-scale device with standard graphite tools of 20 mm inner diameter. Initially, Nb was poured into the pressing die and pre-compacted using uniaxial pressure and then the Nb layer was sintered by FAST/SPS under vacuum

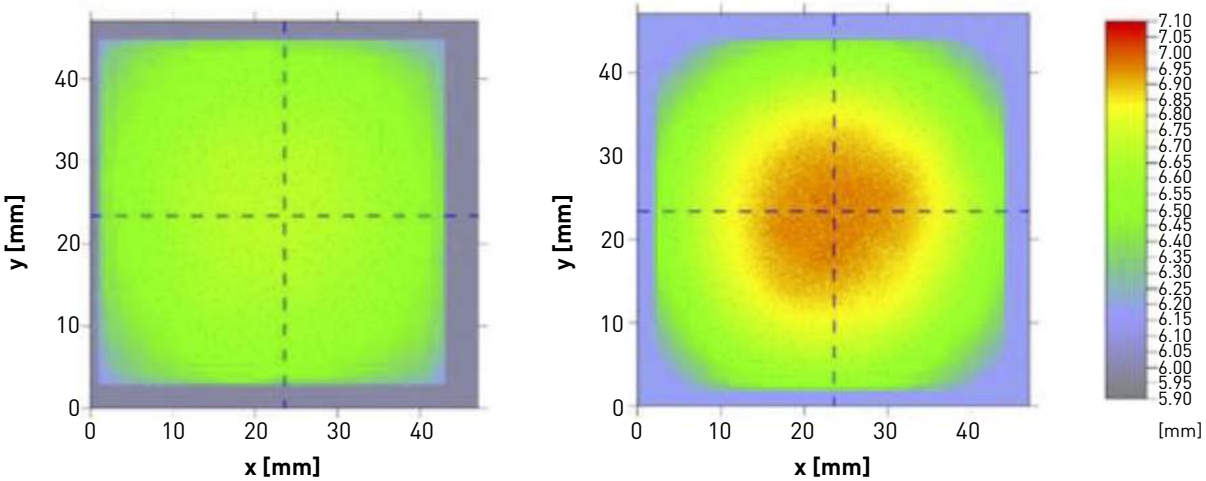
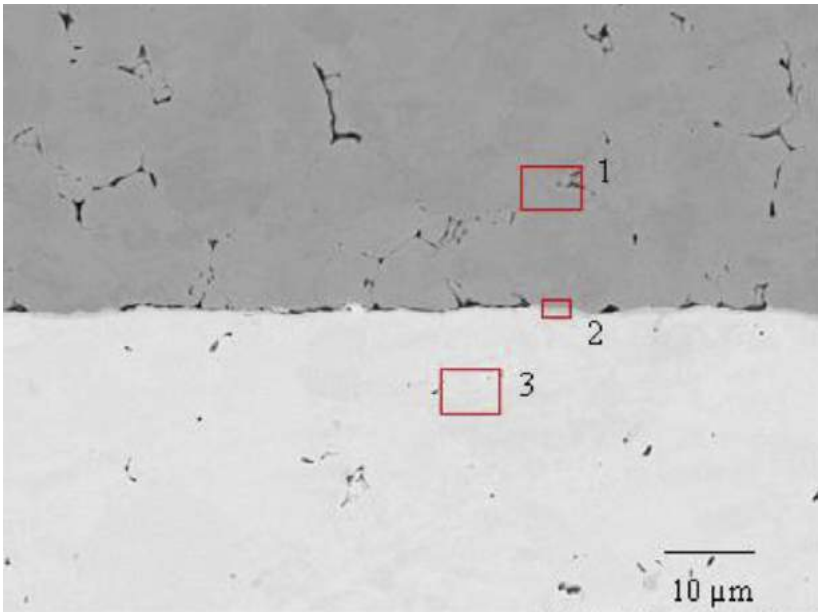


Fig. 8 Optical profilometer analysis of Nb/SS316L composites produced by screen-printing Nb powders on pre-sintered SS316L tapes. Sintering of Nb layer carried out at (a) 1100°C and (b) 1150°C [2]

(ca. 3 Pa) at 1500°C using a uniaxial pressure of 50 MPa with a dwell time of 30 s at sintering temperature. After sintering, the carbide layer was removed by grinding and polishing the Nb part. Then the Nb part was returned to the graphite die, the SS316L powder was added and the mixture was pre-compacted using a uniaxial pressure of 50 MPa for 60 s. Finally, Nb/SS316L composites were sintered by FAST/SPS under vacuum (ca. 3 Pa) at 1000°C with an axial pressure of 50 MPa, the sintering temperature being held for 20 s.

The very short dwell times in sintering in FAST/SPS considerably decreased interdiffusion (Fig. 9), contributing to an avoidance of the formation of secondary phases and carbides. The results obtained to date have indicated that FAST/SPS is a promising route for the production of Nb/SS316L composites for PTLs applications and therefore ongoing work will focus on applying this sintering technique.

Fig. 10 compares the polarisation curves of Nb/SS316L composites with Juelich standard Ti-based PTLs measured in a PEM single cell testing setup. At current densities below 1 A·cm^{-2}, Nb/SS316L composites and Ti-based PTL delivered similar voltages. However, at higher current densities, Nb/SS316L composites showed an increased over-potential. The authors believe that the high over-potential of Nb/SS316L composites was caused by the relatively low porosity of the SS316L layer and the partial flaking of Nb particles; such particles can enter the surface pores and hinder water transport. It is anticipated that, by optimising the porosity and sintering of the Nb layer,



Point	Nb (wt.%)	Fe (wt.%)	Cr (wt.%)	Ni (wt.%)	Mo (wt.%)	Mn (wt.%)
1	97.7	0.1	0.01	0.03	1.9	0.15
2	71.0	17.9	4.2	2.2	4.6	0
3	0.2	70.9	17.2	8.5	2.2	1.0

Fig. 9 SEM image and EDS composition of the cross section of SS316L/Nb composites produced by FAST/SPS. Nb Layer was consolidated at 1500°C and SS316L layer at 1100°C [2]

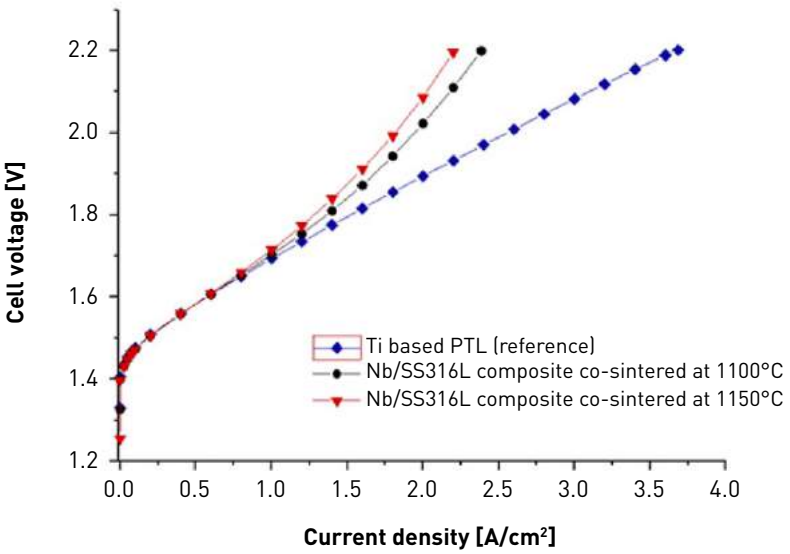


Fig. 10 Polarization curves of Ti-based PTL and PTLs made of Nb/SS316L composites recorded in a PEM single cell [2]

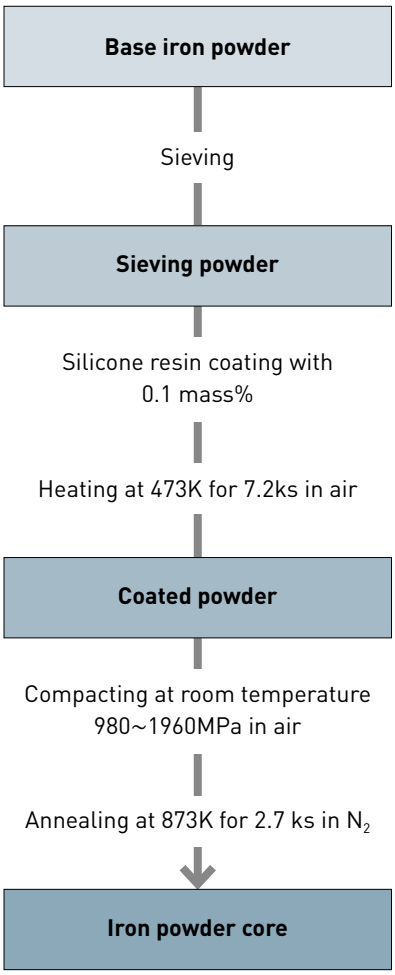


Fig. 11 Preparation process of the iron powder cores [3]

the adherence of Nb particles and the contact between the catalytic layer and the PTL will be improved and consequently the cell performance will be enhanced.

These preliminary results have indicated that Nb/SS316L composites are promising candidates for application as PTLs in PEM electrolysers. However, further studies are required to improve microstructure and to investigate durability and long-term performance of the Nb/SS316L based PTLs.

Influence of iron powder space factor on hysteresis loss of pure iron powder cores

Turning attention to PM magnetic materials, Takuya Takashita (JFE Steel Corporation Steel Research Laboratory, Japan) and Yukiko Ozaki (Kyushu University, Japan) reported on a study of the influence of iron powder space factor on hysteresis loss of pure iron powder cores. [3]

Pure iron powder cores, which are made from insulated iron powder, show lower eddy current losses compared with conventional metal magnetic materials such as electrical steel sheets. With these features, iron powder cores have been applied to devices such as the reactor in hybrid vehicles, with operating frequencies around 10kHz. To expand the application of the iron powder cores, reduction of their hysteresis loss is also required. The most effective method of reducing hysteresis loss is to reduce the pinning sites of domain walls, such as crystal grain boundaries, dislocations and impurity atoms or precipitates, and an increase in space factors, i.e. relative densities, in iron powder cores.

The aim of the reported research was to identify the mechanism of the influence of the space factor of iron powder cores on their hysteresis losses, through magnetic measurements and an electromagnetic simulation.

Iron powder cores were prepared using the process shown in Fig. 11. The chemical composition of the iron powder used is shown in Table 5. The powder was sieved to a particle size range of 106 μm to 150 μm and then coated with 0.10 mass% silicone resin, heated to 473 K for 7.2 ks to harden the resin, and insulating coated powder was prepared. The coated powder was compacted into ring-shaped cores (outer diameter 38 mm, inner diameter 25 mm, height 6 mm). The compaction pressure was varied between 980, 1470 and 1960 MPa. The compacts were annealed at 873 K for 2.7 ks in a nitrogen atmosphere, allowing iron powder cores P1~P3 to be produced.

Low-carbon steel sheet with a thickness of 0.5 mm was prepared by cold rolling from 2.0 mm thick hot rolled sheet. The chemical composition of this steel sheet is also shown in Table 5. From the cold-rolled sheet, four types of specimen with different crystal sizes, E, F, G and H, were produced by annealing at 973 K in a nitrogen atmosphere for 0, 30, 180 or 600 s. The annealed sheets were cut into the ring shape with the same inner/outer diameter as the iron powder cores using an electro-discharge machine.

	Chemical composition (mass%)							
	C	O	S	N	P	Mn	Si	Al
Base iron powder	0.001	0.024	< 0.001	< 0.0005	< 0.002	< 0.010	< 0.010	0.002
Low-carbon Steel sheet	0.001	0.008	< 0.001	0.0018	< 0.002	< 0.010	< 0.010	0.004

Table 5 Chemical compositions of the base iron powder and the base steel sheet [3]

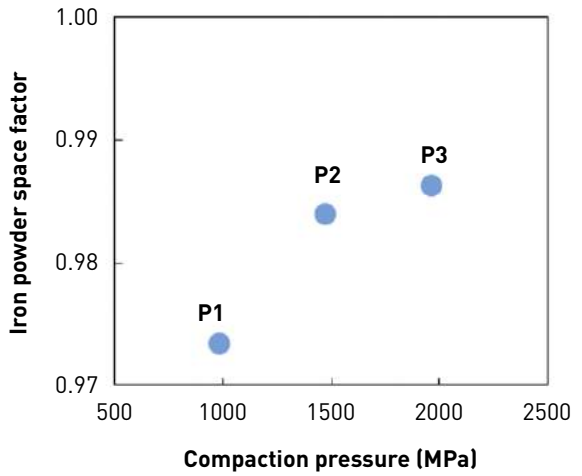


Fig. 12 Relationship between compaction pressure and iron powder space factor [3]

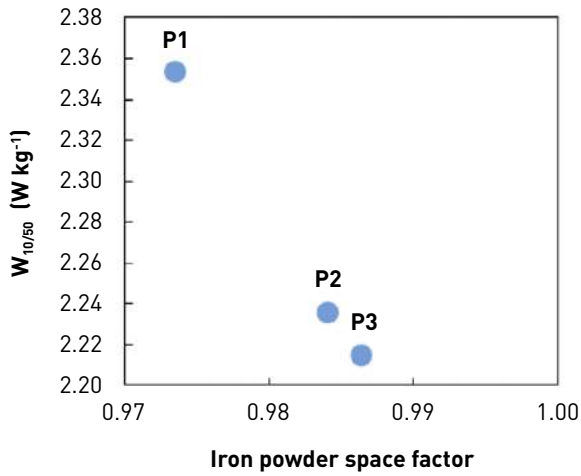


Fig. 13 Relationship between iron powder space factor and hysteresis loss [3]

The iron powder space factors and magnetic path lengths of the cores were calculated from their dimensions and weights and the true density of pure iron (7.87 Mg m^{-3}). The space factors of the iron powder cores are shown in Fig. 12. The space factor increases with an increase in compaction pressure. Crystal grain sizes in the iron powder cores and steel sheet ring cores were measured by the intercept method from optical micrographs of the cross-sectional areas perpendicular to the magnetic path. Measured average crystal grain sizes of the powder cores of P1, P2 and P3 were respectively 30.6, 26.2 and 26.0 µm and the average value of these three cores was 26.7 µm.

Direct current (DC) hysteresis loops of the iron powder cores and steel sheet ring cores were measured with a DC magnetic properties measuring instrument. The primary and secondary coils had 100 and 40 turns, respectively, and φ0.6mm insulated copper wire was used as the coil. In the case of the measurements of the iron powder cores, the maximum magnetic induction was adjusted to 1.0T. In the case of the steel sheet ring cores, the maximum magnetic induction was adjusted between 0.1 to 1.5 T. The hysteresis losses were evaluated from the measured hysteresis loops.

The relationship between space factor and hysteresis loss is shown in Fig. 13. The hysteresis loss decreased with an increase in iron powder space factor.

Hysteresis losses of steel sheet ring cores are shown in Fig. 14. Hysteresis loss increased with an increase in magnetic flux density in

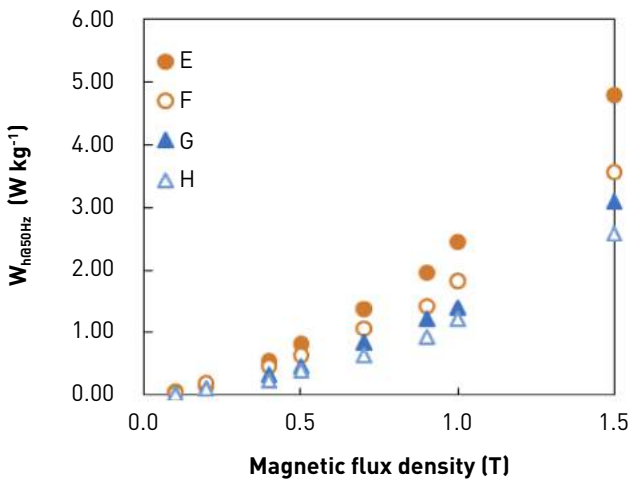


Fig. 14 Hysteresis losses of steel sheet ring core [3]

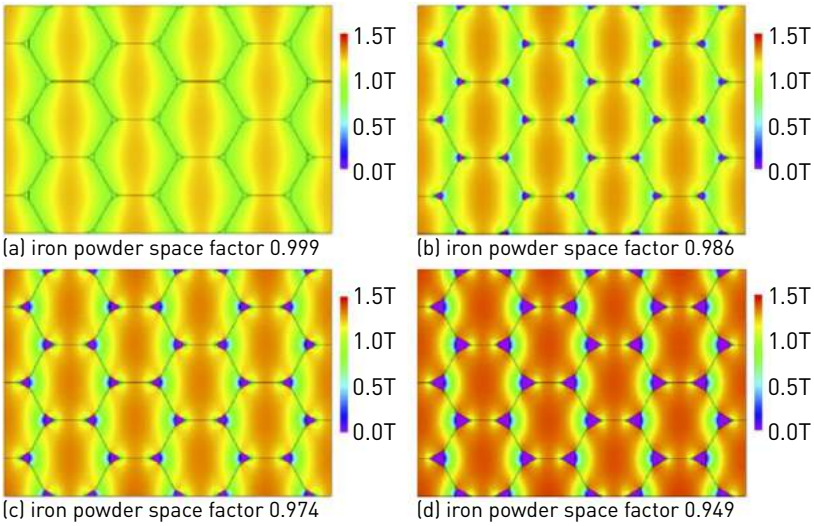


Fig. 15 Contour map of magnetic flux density (average magnetic flux density: 1.0T) [3]

each specimen. Measured average crystal grain sizes of the steel ring cores E, F, G and H were respectively 19.4, 30.1, 52.6 and 84.1 μm.

To evaluate the magnetised condition in the iron powder core, electromagnetic field analysis by the finite element method (FEM) was performed. The diameter of particles was 128 μm, which was regarded as the average particle size of the iron powder used. The thickness of insulation layer on each particle was estimated as 80 nm from the specific surface area of the iron powder particles used and the volume fraction of the resin coated on them. The particles were arranged in a hexagonal structure and the pores at the triplet points were approximated as equilateral triangles with sides of 0.0, 6.2, 8.4, and 11.7 μm, based on porosities of 0.001, 0.014, 0.026, and 0.500, respectively. In the calculation, the permeability of iron was obtained from the DC magnetisation curve of steel sheet ring cores and the pores and the insulating layers were regarded as a vacuum.

Contour maps obtained by electromagnetic analysis are shown in Fig. 15. Low magnetic flux density areas were observed around the pores and high magnetic flux density areas were concentrated inside the particles. The histogram of the magnetic flux density was shown in Fig. 16. The histogram includes not only iron powder particles, but also pores. Several areas were over 1.0 T, which is the average magnetic flux density of the analysed mode and, in addition, the area over 1.0 T increases with a decrease in iron powder space factor. From the electromagnetic analysis, the area with higher magnetic flux density than 1.0 T was observed and this area might affect the hysteresis loss. Therefore, a method was proposed by the authors to estimate the level of increase in hysteresis loss by the area.

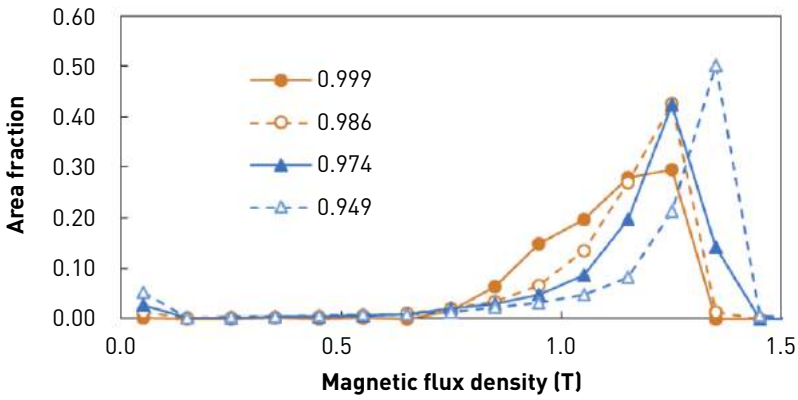


Fig. 16 Histogram of magnetic flux density fron contour maps [3]

Firstly, the model equation of hysteresis loss estimated by magnetic flux density and crystal grain size was derived from the experimental values of steel sheet ring cores (which have the space factor of 1) on the basis of the relationship proposed by Steinmetz.

$$W_h = k_h \cdot f \cdot B^{1.6} \qquad \text{[Equation 1]}$$

where B is magnetic flux density, f is frequency and k_h is the coefficient depending on the magnetic hysteresis of the core. It has been suggested that hysteresis loss of iron powder core might be proportional to the inverse of average crystal grain size d_i experimentally. Therefore, k_h can be replaced as follow.

$$W_h = (A/d_i + C) \cdot f \cdot B^{1.6} \qquad \text{[Equation 2]}$$

where A and C are coefficients defined experimentally from the hysteresis losses of steel sheet ring cores (Fig. 14) and Equation 2. These coefficients are estimated as A=0.58 and C=0.02 and calculated hysteresis losses are in good agreement with measured hysteresis losses in Fig. 14.

Then, the hysteresis loss of iron powder core based on the electromagnetic analysis (which has the distribution of magnetic flux density) is estimated as the sum of the product of area fraction and hysteresis loss of each magnetic flux density as follow.

$$W_{h\_s10/50} = (S_0 \cdot W_{h0/50} + S_{0.5} \cdot Wh_{0.5/50} + \cdots + S_{15} \cdot Wh_{15/50}) \qquad \text{[Equation 3]}$$

where S_0 ~ S_{15} are area fractions with magnetic flux density from 0 to

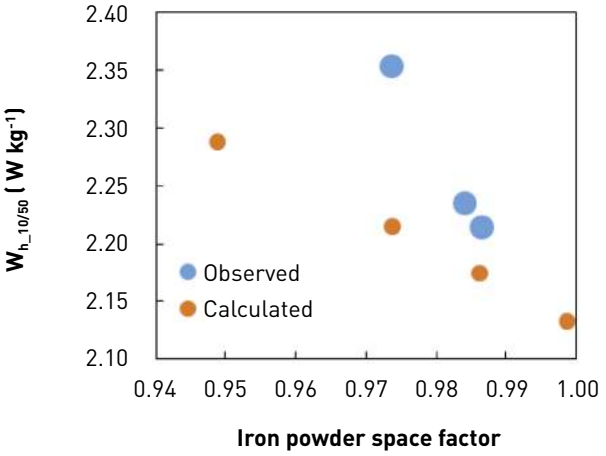


Fig. 17 Observed and calculated $W_{h\_10/50}$ [3]

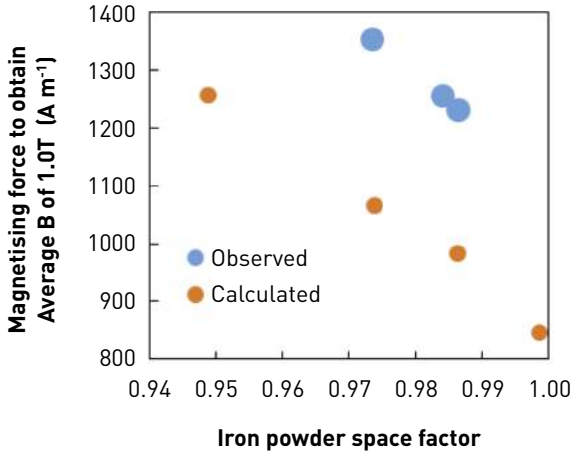


Fig. 18 Relationship between iron powder space factor and magnetising force to obtain average B of 1.0T [3]

1.5 T (as shown in Fig. 16) and $W_{h0/50}$ ~ $Wh_{15/50}$ are hysteresis losses with magnetic flux density from 0 to 1.5 T.

The calculated hysteresis loss from Equation 3 is show in Fig. 17. Hysteresis loss increases with a decrease in iron powder space factor. Experimental values for iron powder cores (from Fig. 13) also shown in Fig. 17. While both the calculated and experimental values decrease with an increase in space factor, the experimental values are higher than the calculated values. This means that an increase in hysteresis loss is not only dependent on the distribution of magnetic flux density but also on other factors. Possible factors are the incorrect estimation of the thickness of the insulation layer or the magnetic domain structure.

In relation to the former factor, the relationship between iron powder space factor and magnetisation force to obtain an average magnetic flux density of 1.0 T is shown in Fig. 18. The experimental value is higher than calculated value. This suggests that the magnetic gap in the circuit of the actual iron powder core is larger than that of the calculation model. Therefore, the actual iron powder has a larger magnetic flux distribution than calculation model and this might lead to higher hysteresis loss.

In relation to the latter factor, the actual magnetic material magnetises by domain wall movement, unlike the magnetisation in the calculation model. From the electromagnetic analysis, the area around the pore is difficult to magnetise because of a demagnetising field. This suggests circumvention of magnetic flux around the pore, which might lead to the nucleation of an extra magnetic domain around the pore and an increase in coercive force and hysteresis loss.

The quantitative separation of these two factors was difficult in this research and the authors have proposed that further electromagnetic analysis and magnetic domain observation may be required.

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