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POWDER METALLURGY REVIEW

HÖGANÄS HYBRID TEARDOWN

CHARACTERISING POWDERS FOR CIP

JPMA AWARD-WINNING PARTS

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POWDER METALLURGY REVIEW

Identifying applications for Powder Metallurgy

Many opportunities for Powder Metallurgy are still to be realised in today's automotive market. For various reasons, not every viable component that could be made by PM is.

Even when there are clear economic and performance advantages, the PM process is not always first choice. However, as the auto industry moves further towards hybrid and electric power systems, just what can actually be made by PM is changing.

To document the use of PM in the latest automotive drivelines, and identify viable opportunities for future adoption, engineers at Höganäs in China recently completed a teardown of a hybrid-electric vehicle.

The results proved interesting, with Höganäs identifying no less than 120 components suited to the PM process. Of course, the challenge for the PM industry is now to convert these opportunities into reality. Read the full report on page 51 to learn more.

Paul Whittaker
Editor, *Powder Metallurgy Review*

Cover image
Engineers at Höganäs China completed a teardown of a hybrid-electric car (Courtesy Höganäs)

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 www.kymerainternational.com

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POWDER METALLURGY REVIEW


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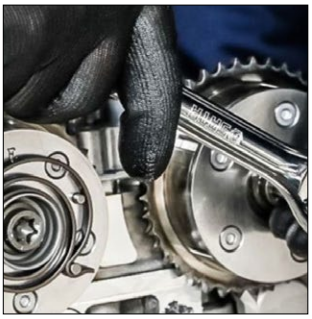
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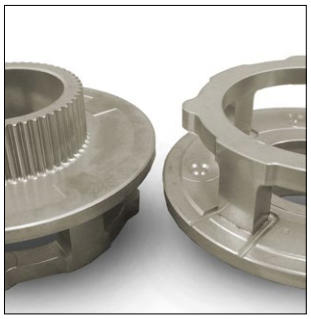
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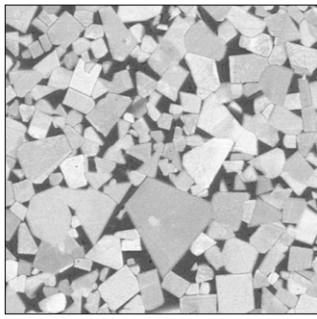
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51 **Teardown showcases applications for Powder Metallurgy in hybrid electric vehicles**

Following on from a teardown project in 2017, where a team of engineers at Höganäs AB stripped back three new vehicles to their component parts, the company recently repeated the exercise with a hybrid SUV from Chinese automaker BYD. The four-wheel drive BYD Tang is built for China's domestic market, and provided the team at Höganäs with the opportunity to establish a better understanding of the use of Powder Metallurgy in hybrid vehicles.

61 **Characterising powders for Cold Isostatic Pressing applications**

An understanding of the characterisation of metal powders is essential for optimising production of high-quality components during Cold Isostatic Pressing. In this article, Freeman Technology's Jamie Clayton and Jason Dawes present an overview of the main powder characterisation processes used in industry, and make the case for the company's dynamic powder testing technology.

69 **JPMA Awards 2019: Showcasing innovations in PM for high-volume applications**

The winners of this year's Japan Powder Metallurgy Association Awards highlighted the continual developments being made by to further expand the use of PM technology. The winners demonstrated the potential for new applications in the automotive sector, as well as other high-volume application areas.

77 **Euro PM2019: Manipulating the sintered microstructures of hard materials**

A technical session at the EPMA's Euro PM2019 Congress in Maastricht examined a variety of means to manipulate the sintered microstructures of hard materials. In this report, Dr David Whittaker provides an overview of the presentations and highlights the work undertaken.

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

Powder Metallurgy on show as EPMA celebrates 30 years

This year, the European Powder Metallurgy Association held the Euro PM2019 Congress & Exhibition in the Dutch city of Maastricht. Attracting over 1100 attendees from over forty countries, the event also saw the association celebrate its 30th Anniversary.

As in recent years, a high number of abstracts from across the Powder Metallurgy community made for three days of presentations, discussions and networking opportunities. The all topic event represented all areas of Powder Metallurgy, with over 300 oral and poster presentations. Running in parallel to the technical sessions was the Euro PM Exhibition, home to over one-hundred exhibiting companies representing the full PM supply chain.

Ralf Carlström, EPMA's new President, opened the Plenary Presentations with an 'Overview of the status and trends in the European PM industry'. This was followed by a welcome from the Congress Co-Chairmen Prof Christoph Broeckmann, Director of the Institute for Materials Applications in Mechanical Engineering, RWTH Aachen University, and Dr Henk van den Berg, Consultant. The Technical Program Committee Chairs, Prof Jie Zhou, Associate Professor, Delft Technical University and Prof Francisco Castro, CEIT, and Dr Anke Kaletsch, Head of Powder Technology, RWTH Aachen University, thanked the technical programme committee members who reviewed over 350 technical papers.

The opening session began with a presentation, 'Graphite - the wondrous mineral in PM' from Stephen A Riddle, CEO, Asbury Graphite & Carbons, followed by a presentation on 'Powder based laser processes in the context of digital photonic production and Industry 4.0' by Prof Johannes Schleifenbaum, Chair of Digital Additive Production, RWTH Aachen.

The annual Euro PM event concluded on Wednesday evening, with a special 30th Anniversary Closing Drinks Reception, prior to the annual Congress Dinner.

Thirty years promoting Europe's Powder Metallurgy industry

Founded in June 1989, the European Powder Metallurgy Association was created to 'Promote, Develop and Represent' the Powder Metallurgy industry throughout Europe. Since then, the EPMA has grown to not only represent the press and sinter sector for which it was established, but all metal powder-based sectors including Metal Injection Moulding, hard materials, Hot Isostatic Pressing and Additive Manufacturing.

In addition to organising the successful Euro PM congress series, the EPMA runs a number of seminars, short courses and summer schools, along with publishing numerous titles on the various metal powder based technologies it represents.

www.epma.com

Carpenter Technology continues year on year growth

Carpenter Technology Corporation, Philadelphia, Pennsylvania, USA, has announced financial results for its fiscal first quarter ended September 30, 2019. The company reported Q1 2020 net income of $41.2 million, a significant increase from $31.5 million in Q1 2019. Net sales for Q1 2020 were $585.4 million compared with $572.4 million in the first quarter of fiscal year 2019.

The Performance Engineered Products (PEP) division, which includes Carpenter's Dynamet titanium business, Carpenter Powder Products business, Amega West and Carpenter Additive, reported net sales of $109.4 million, down slightly from $111.7 in Q1 2019.

In its Specialty Alloys Operations (SAO) division, comprised of Carpenter's major alloy and stainless steel manufacturing operations, the company reported net sales of $491.1 million, up from $475.5 million in Q1 2019.

"Our first quarter results represent our 11th consecutive quarter of year-over-year earnings growth and our best first quarter operating income performance in six years," stated Tony Thene, Carpenter Technology's President and CEO. "Our solutions approach continues to drive a richer product mix and strong performance at SAO, where we delivered record first quarter operating income. In addition, we received one additional qualification for our Athens facility during the quarter and customer engagement levels remain high."

"The first quarter also marked our 11th consecutive quarter of year-over-year backlog growth, including healthy increases in our key aerospace and defence and medical end-use markets," he added."Moving forward, our strategic focus is centred on strong commercial execution and securing capacity gains and manufacturing improvements via the Carpenter Operating Model. We also continue to operate with a sharp eye on the future and ensuring we best position Carpenter Technology for sustainable long-term profitable growth," he stated.

"To that end, we have built an end-to-end Additive Manufacturing platform and customer collaborations continue to rapidly increase. In addition, the expansion of our soft magnetics capabilities remains on target as we look to capitalise on our high-value portfolio and the expected disruptive impact of electrification. We believe these investments in critical emerging technologies are necessary to sustain our position as a leading solutions provider and critical supply chain partner for our customers in the years and decades to come," he concluded.

www.carpentertechnology.com

Liberty Powder Metals begins construction of new atomiser facility

Liberty House Group, parent company of Liberty Powder Metals, Sheffield, UK, has begun construction of a powder metals development facility in Teesside, UK, which it hopes will enable the group to expand its reach in specialist metals and materials.

The new powder metals facility will be based at the Materials Processing Institute in South Bank, Middlesbrough, UK, and an initial £10 million is also being invested to establish the Liberty Powder Metals business in this location. This investment will include a state-of-the-art vacuum induction inert gas atomiser (VIGA), for which Liberty Powder Metals secured funding from the Tees Valley Combined Authority Cabinet, UK. There are also plans to install a range of sieving, blending, packaging and analytical equipment at the facility.

It was stated that the atomiser will enable the group to develop a new generation of powdered steels and enhance its position in the supply chain for precision steel components used in rapidly-changing and advanced sectors such as aerospace, automotive, energy and specialist industrial equipment.

Dr Simon Pike, General Manager of Liberty Powder Metals, stated, "We are grateful to our partners for the work they have done to reach this stage. Finance from Tees Valley Combined Authority has been critical in making the project a reality and I look forward to continuing all our partnerships to make Teesside a global-leading centre of expertise for powder metal production."

"We are glad to see construction now starting," commented Chris McDonald, Chief Executive Officer for the Materials Processing Institute. "Advanced materials development is a core area of research at the institute and this investment by Liberty Powder Metals is an example of the benefits of partnerships and collaborations between industry and the Institute."

Tom Sellers, Commercial and Business Development Manager for Liberty Powder Metals, added, "We are excited about the progress to date and I am looking forward to bringing our products to market and developing our customer base along with the strength of the Liberty brand."

Atomising Systems Ltd and Consarc Engineering designed the equipment for the powder metals facility, while K-Home International is managing the installation at the Materials Processing Institute.

www.libertyhousegroup.com
www.atomising.co.uk

GKN Powder Metallurgy sales dip due to General Motors strike

Melrose Industries PLC, UK, has published a trading update for its third quarter, July 1 to October 31, 2019, in which it states that its GKN Powder Metallurgy division was impacted by the temporary effects of the General Motors strike, leading to a sales decline of 13% when compared to the same period last year. However, the company stated that, without the strike, revenue would have been in line with the Board of Directors' expectations.

Melrose confirmed that during the trading period, contracts were exchanged to acquire Forecast 3D, an Additive Manufacturing company which had sales of $19 million in 2018. The acquisition is expected to complete by the year end and will reportedly further expand GKN Powder Metallurgy's capabilities in this growing market.

The GKN Aerospace division was reported to have achieved sales growth of over 5% in the quarter, compared to the same period last year, outperforming the board's expected longer term average growth rate. In addition, good margin improvement has been delivered compared to the same period last year.

GKN Automotive also delivered a higher profit and margin in the period compared to the same period last year. Sales were reported to be down 5% year-on-year, however, which also included the temporary effect of the General Motors strike in the USA.

Melrose stated that group net debt was in line with the board's expectations, with significant investment and restructuring actions being funded to further improve performance and initial steps to reduce working capital in GKN being implemented as planned.

Justin Dowley, Chairman of Melrose, stated, "Melrose continues to do what it has always done well: improve businesses. Some macro conditions could be more helpful, but this has not stopped us continuing to transform the GKN businesses, delivering another trading period in line with expectations, and achieving better trends than seen in the first half of the year. We are excited about what is possible and confident in our ability to unlock significant further shareholder value."

Melrose acquired GKN plc, including GKN Powder Metallurgy, the world's largest producer of Powder Metallurgy components, for £8.1 billion in April 2018.

www.gknpm.com
www.melroseplc.net

Stefan Widing announced as new CEO of Sandvik

Sandvik's Board of Directors has announced Stefan Widing as the company's new President and CEO, effective February 1, 2020. The appointment follows the previous announcement that current President and CEO, Björn Rosengren, will leave the company.

Stefan Widing assumes the position of Sandvik CEO as of February 1, 2020 (Courtesy Sandvik)

Widing has served as Executive Vice President of Assa Abloy and President of HID Global Corporation, a technology division within Assa Abloy, since 2015. He holds an MSc in Applied Physics and Electrical Engineering and a bachelor's degree in Business Administration. Formerly, he served as General Manager for Assa Abloy's Shared Technologies, and before that held various positions in Assa Abloy and SAAB Aerospace.

"We are very pleased that Stefan Widing will take on the position as President and CEO of Sandvik. Stefan is a highly appreciated leader with a solid industrial track record of developing organisations and businesses, both organically and through acquisitions," stated Johan Molin, Chairman of the Sandvik Board of Directors.

"In addition, his competence in advanced technologies and experience from leading digital transformations will be another valuable asset to Sandvik," he continued. "Stefan definitely has the capabilities needed to continue the decentralised way of working and to ensure Sandvik's future development."

"I really look forward to joining Sandvik," Widing commented. "I'm convinced that such a technologically advanced industrial group, recognised for its very competent employees, has a lot of future potential not the least by further developing within the digital area and exploring new technologies, thereby leveraging efficiency, productivity and sustainability even more for its customers."

www.home.sandvik

Miba Friction breaks ground on expansion to Slovakia site

Miba Steeltec, a segment of Miba Friction Group, has broken ground on an expansion to its site in Vráble, Slovakia. The company is investing approximately €10 million into the project, which is expected to enlarge the manufacturing space to around 16,500 m^2. In addition to that, the new building will include around 600 m^2 office space, along with a new research and development facility.

The ground-breaking ceremony at Miba Friction's new site was attended by Tibor Toth (Mayor of Vrable), Patrik Rac (Site Manager, Miba Steeltec), Ferdinand Pranckh (Managing Director Operations, Miba Friction Group), Margit Bruck-Friedrich (Austrian Ambassador to Slovakia), Martin Liebl (General Manager, Miba Friction Group), Hans Christian Kügerl (Austrian Trade Commissioner in Slovakia) (Courtesy Miba Friction Group)

Within the Miba Group, Miba Steeltec is said to be an important high-tech production site for friction technology for powertrains, axis and brakes in construction machinery, as well as tractors or mining machinery, and components for the automobile industry and four-wheel drive vehicles. The company is a supplier to customers including John Deere, Caterpillar, Volvo, ZF, AGCO, GKN and Gima.

The research and development premises on the expanded site will serve as the first R&D-department for Miba Friction Group outside of Austria. Since its founding in 2007, Miba Friction stated that it has invested €60 million in Miba Steeltec in Vráble, with revenues at the site having grown from €20 million in 2007 to €73 million in the most recent fiscal report.

Construction work is expected to be finished by the end of the year. Subsequently, production equipment will be relocated and set up, with finalisation of the building planned for early summer 2020.

www.miba.com

Hyperion acquires cemented carbide company Arno Friedrichs Hartmetall

Hyperion Materials & Technologies Inc., a materials science company headquartered in Worthington, Ohio, USA, reports that is has signed an agreement to acquire Arno Friedrichs Hartmetall GmbH & Co. KG (AFC), Mainleus, Germany, and its affiliates, a supplier of cemented carbide blanks used in the manufacture of high-precision rotary cutting tools for drilling and milling applications.

The company states that at the close of the transaction, Arno Friedrichs, the company's founder, will step down as CEO and join the Board of Directors of Hyperion, where he will contribute to the development of the combined business with his industry knowledge and expertise. Ralf Greifzu, AFC Executive, has led global sales at the company for seven years and will reportedly replace Friedrichs as VP and General Manager of AFC.

Ron Voigt, CEO of Hyperion, stated, "We are thrilled to combine AFC's leading innovation capabilities and differentiated manufacturing processes with Hyperion's deep application expertise and materials science capabilities."

"AFC is a premier producer of cemented carbide rotary tool blanks with an exceptionally talented workforce and a great reputation for supporting their customers and addressing their most challenging needs," he continued. "In combining the talent and capabilities of both companies, we will be able to enhance our product offering through customer-focused innovation and provide even greater value to our customers."

"It is with great pleasure that I announce our partnership with Hyperion," commented Arno Friedrichs, founder of AFC. "Given our shared focus on providing best-in-class products to finished tool manufacturers, this partnership is a perfect fit. The combination will strengthen both companies and support AFC's continued development."

The transaction was expected to close in the fourth quarter of 2019.

www.hyperionmt.com
www.afcarbide.de

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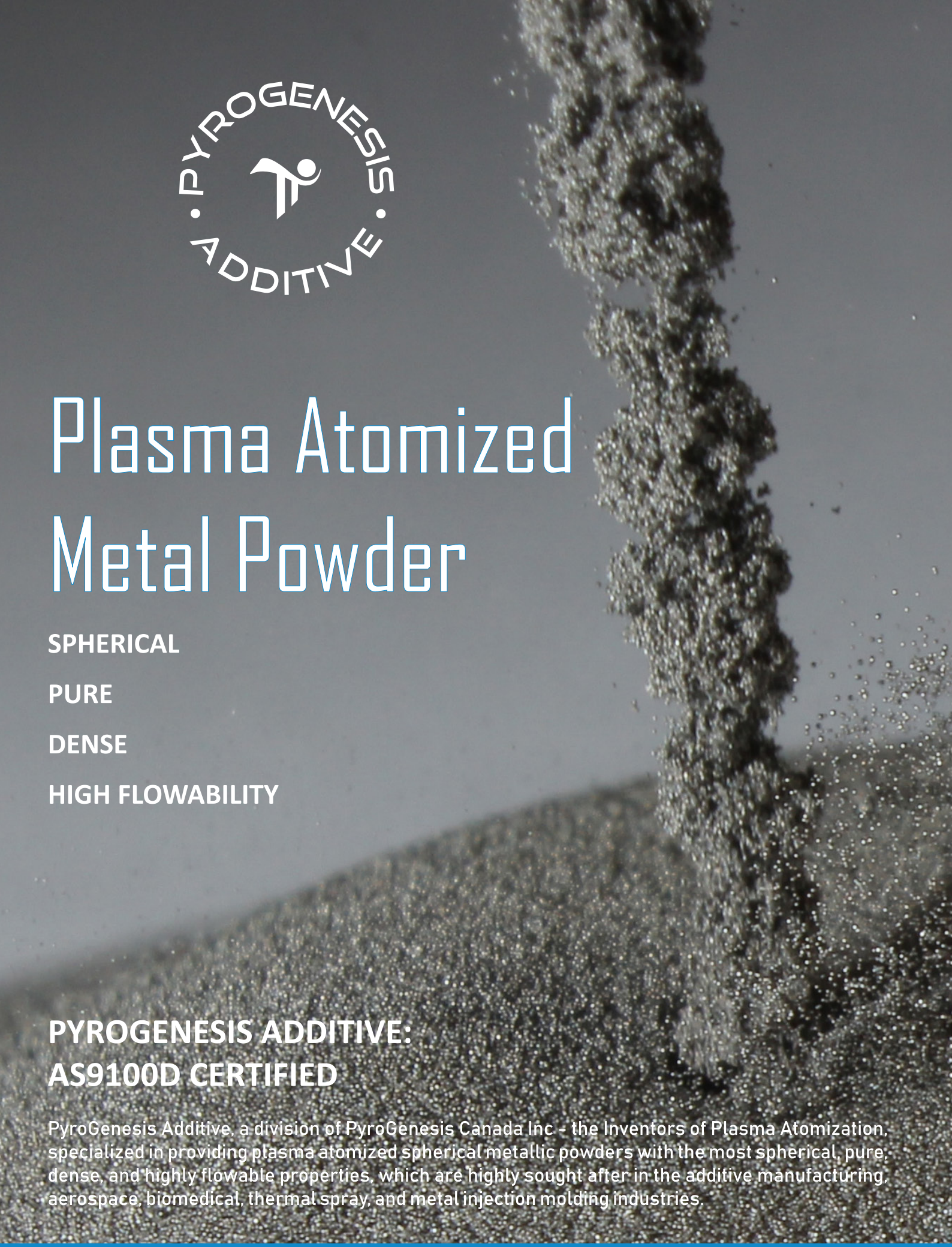

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www.pyrogenesis.com/products-services/contact-pyrogenesis-additive/

H.C. Starck reports increased tungsten powder sales

H.C. Starck Group, Munich, Germany, has reported a significant increase in its sales for fiscal year 2018, with total sales at €691.7 million. Adjusted to account for the sale of its Tantalum & Niobium and Surface Technology and Ceramic Powders (STC) Divisions during the year, sales were said to have risen by 23% to €581.7 million.

The company stated that the most important external factor was a positive economic environment in the end-user industries. Enhanced sales efforts, advances in technology and productive cost initiatives were also said to have contributed to its success.

H.C. Starck's tungsten division, H.C. Starck Tungsten GmbH, posted an increase in sales in 2018 said to reflect the market success of its nanocrystalline tungsten carbide varieties and the ongoing ramp-up of capacity at its Chinese plant. Numerous projects designed to help increase efficiency, such as the optimised utilisation of worldwide plant capacities and the improvement and development of various production processes, were also key to its performance.

www.hcstarck.com

New 80 kN electric powder press from Osterwalder

Osterwalder AG, Lyss, Switzerland, has launched a new 80 kN electric powder press. Capable of up to forty strokes per minute, the new SP 80 is said to be ideal for the production of ISO inserts and similar parts.

The compact-sized press is reported to offer safe and easy powder refill during operation, thanks to an accessible powder hopper and filling shoe. The press includes an integrated cooling system with water-cooled drives. A fixed die aids setup with insert handling systems.

"If you want to increase your production capacity or replace older presses, the SP 80 is the most attractive solution in the market," the company stated. "The performance of our clients, producing high-quality parts in combination with unmatched cost structure is our approach, our target."

www.osterwalder.com

Osterwalder's SP 80 is said to be ideal for the production of ISO inserts and similar parts (Courtesy Osterwalder)

Construction begins on new Höganäs atomising plant for AM powders

Sweden's Höganäs AB has begun constructing its new atomising plant for the production of high-purity metal powders for the Additive Manufacturing industry. The powders produced will be sold globally under the trademark Amperprint®.

The plant is based at the Laufenburg production unit in Germany and completion is scheduled for the third quarter of 2020. The Freiburg Regional Council is said to have approved the construction and operation of the plant under the conditions of the German Federal Emission Control Act (BImSchG) in September.

Currently, Höganäs has a yearly metal powder production capacity of 500,000 tons. The company operates eighteen production centres worldwide and has a workforce of 2,500 employees.

"The investment in the million-euro plant will help us to significantly increase our market share for metal powders in the promising segment of 3D printing," stated Peter Thienel, Höganäs' Site Manager. "In addition, we want to further increase the attractiveness of Höganäs as an employer in Germany and are confident that we can continue to offer our co-workers long-term professional development."

www.hoganas.com

Peugeot & Fiat Chrysler merger to result in world's fourth largest auto company

Plans have been announced that will see auto makers Peugeot S.A (Groupe PSA) and Fiat Chrysler Automobiles (FCA) merge, creating the fourth largest global OEM in terms of unit sales, with combined revenues of almost €170 billion.

The companies stated that the Supervisory Board of Peugeot S.A. and the Board of Directors of Fiat Chrysler Automobiles have each unanimously agreed to work towards a full combination of their respective businesses by way of a 50/50 merger. Both boards have given the mandate to their respective teams to finalise discussions to reach a binding Memorandum of Understanding (MoU) in the coming weeks.

The plan to combine the Groupe PSA and FCA businesses is said to follow intensive discussions between the senior managements of the two companies. Both reportedly share the conviction that there is compelling logic for a bold and decisive move that would create an industry leader with the scale, capabilities and resources to effectively manage the challenges of a new era in mobility.

With combined unit sales of around 8.7 million vehicles, there is estimated to be approximately €3.7 billion in annual run-rate synergies derived principally from a more efficient allocation of resources for large-scale investments in vehicle platforms, powertrain and technology, and from the enhanced purchasing capability inherent in the combined group's new scale. It was added that these synergy estimates are not based on any plant closures.

The shareholders of each company would own 50% of the equity of the newly combined group and would therefore share equally in the benefits arising from the combination. The transaction would be effected by way of a merger under a Dutch parent company and the governance structure of the new company would be balanced between the contributing shareholders, with the majority of the directors being independent.

The board would be composed of eleven members. Five board members would be nominated by FCA (including John Elkann as Chairman) and five would be nominated by Groupe PSA (including the Senior Independent Director and the Vice Chairman). The Chief Executive Officer would be Carlos Tavares for an initial term of five years, and he would also be a member of the board.

"This convergence brings significant value to all the stakeholders and opens a bright future for the combined entity. I'm pleased with the work already done with Mike and will be very happy to work with him to build a great company together," stated Tavares.

Mike Manley, CEO of FCA, added, "I'm delighted by the opportunity to work with Carlos and his team on this potentially industry-changing combination. We have a long history of successful cooperation with Groupe PSA and I am convinced that together with our great people we can create a world class global mobility company."

The new group's Dutch-domiciled parent company would be listed on Euronext (Paris, France), the Borsa Italiana (Milan, Italy) and the New York Stock Exchange (USA), and the group would continue to maintain significant presences in its current operating head office locations in France, Italy and the USA.

www.groupe-psa.com
www.fcagroup.com

Sandvik to divest majority of Sandvik Drilling and Completions

Sandvik AB, Stockholm, Sweden, has signed an agreement to divest the majority of Sandvik Drilling and Completions - which the company formed following its acquisition of Varel International Energy Services, Inc. in 2014 - to private equity firm, Blue Water Energy and its co-investor, the privately-owned Nixon Energy Investments. Sandvik will reportedly remain a minority owner of 30% of the company and hold a position on the board.

According to the company, the contribution to Sandvik's earnings per share from the envisaged minority ownership, reported in associated companies, would have been limited based on the twelve-month period ending September 2019. The purchase price for the 70% share of Sandvik Drilling and Completions related to the oil and gas industry now divested by Sandvik, is SEK 900 million on a cash and debt free basis, implying an enterprise value of SEK 1,250 million for the total business.

Upon closing, the divestment is expected to generate a positive cash flow impact of an estimated SEK 700 million, net of expected transaction costs. Sandvik Drilling and Completions will remain consolidated in the financial statements of Sandvik Mining and Rock Technology until closing of the transaction, which is expected during the first quarter of 2020, and is subject to the approval of relevant authorities.

"In line with our strategy, we continue to focus Sandvik's business portfolio to core areas," stated Björn Rosengren, President and CEO of Sandvik. "While Sandvik keeps the mining related part of Drilling and Completions, the oil and gas related operations will now receive full attention from its new owners to support profitable growth."

www.home.sandvik

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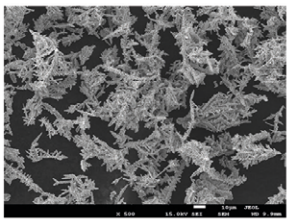
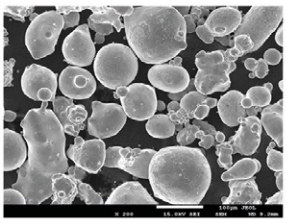
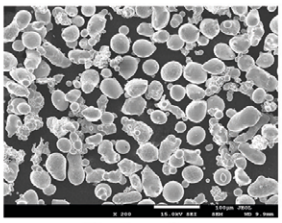


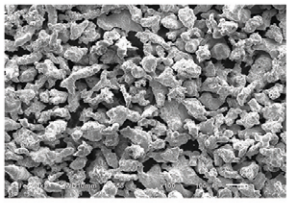
Electrolytic Copper Powder



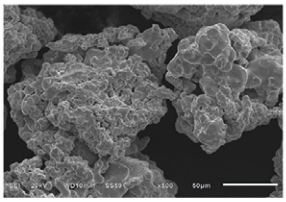
Atomized Copper Powder



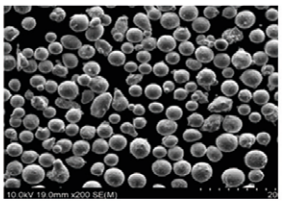
Tin Powder



Copper Alloy Powder



Diffusion Powder



3D Printing Copper Alloy Powder

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  - –dendritic
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- **Tin**
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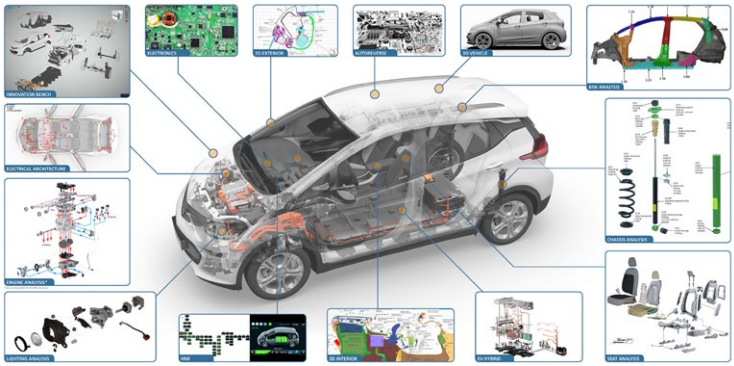
EPMA event to showcase PM automotive applications



The EPMA, in conjunction with A2Mac1, will showcase Powder Metallurgy parts used in current automobiles (Courtesy A2Mac1)

The European Powder Metallurgy Association (EPMA), in conjunction with automotive benchmarking specialists A2Mac1, will showcase the wide range of Powder Metallurgy parts used in today's automobiles at a special one-day event at A2Mac1's facility in Hary, France, on January 15, 2020. In addition to identifying current PM applications, the organisers will highlight many other parts from the 2,000 on display that could benefit from being produced by metal powder.

Aimed at bringing PM parts makers and design engineers from the auto industry together, the event will include presentations from experts explaining the Powder Metallurgy process, its advantages and how it compares with competing technologies. Among those topics discussed will be what to consider when designing parts for PM, along with overviews of Metal Injection Moulding and Additive Manufacturing technologies. A further presentation will look at what PM technology can bring to the design of future powertrains, be they hybrid or pure electric.

Participants will be able to learn more about the entries in the showcase and discuss them one-to-one with the PM experts on hand during the day.

An optional dinner will be held prior to the event on the evening of January 14. The deadline for registration is January 7.

www.seminars.epma.com
www.a2mac1.com

Metal Powder Industries Federation elects new president

Dean Howard, PMT, President of North American Höganäs Co., a subsidiary of Höganäs AB, Hollsopple, Pennsylvania, USA, has been elected the 30th president of the Metal Powder Industries Federation (MPIF), succeeding John F Sweet, PMT, FMS Corporation, Minneapolis, Minnesota, USA. His two-year term began at the conclusion of the Federation's annual Powder Metallurgy Management Summit and 75th Annual MPIF Business Meeting, October 26–28, 2019, in Miami, Florida, USA.

Howard has worked for North American Höganäs Co. for nearly twenty years. He most recently served as president of the MPIF's Metal Powder Producers Association (MPPA), and has served the association actively for many years, receiving the MPIF's Distinguished Service to Powder Metallurgy Award at POWDERMET2017.

He has also been a member of APMI International for twenty-six years, and has served as Chairman of APMI's Southeast Chapter and as APMI International President (2010–2014). He received certification as a Level I Powder Metallurgy Technologist in 1998.

The MPPA also instated a new president following the summit. Jill Spaulding, Kymera International, Research Triangle Park, North Carolina, USA, will serve a two-year term as the association's president.

www.mpif.org

Dean Howard has been elected as MPIF President (Courtesy MPIF)

Mikael Bratt joins Höganäs Board of Directors

Höganäs AB has reported that Mikael Bratt, President and CEO of Autoliv Inc, Sweden, has joined the Höganäs Board of Directors.

Bratt has worked for Autoliv since 2016, said to be the world's largest automotive safety supplier with a market share of 40% and sales amounting to US$8.7 billion. His previous positions include that of Executive VP and Head of Group Trucks Operations at AB Volvo Group, Group CFO and Senior VP of AB Volvo Group, VP and Head of Corporate Finance at AB Volvo Group.

Kurt Jofs, Chairman of the Board stated, "We welcome Mikael to the Höganäs Board. His broad industrial experience, and in particular from the automotive industry, makes him a strong addition to the team."

www.hoganas.com

Nichols Portland opens new facility for its Pump Division; expands pressing capabilities

Nichols Portland LLC, Portland, Maine, USA, a leading manufacturer of Powder Metallurgy components and assemblies used in fluid transfer and other applications, has opened a new facility for its Pump Division in South Portland. The newly-renovated facility will house an extensive laboratory for hydraulic testing, niche pump manufacturing facilities and office space.

PM components will continue to be manufactured at the company's existing Congress Street facility, while Pump Operations will be relocated to the new facility. The 20,000 ft^2 (1,860 m^2) facility will also include space for additional manufacturing equipment required for the company's new business, supplying its products to OEMs in North America and Europe.

Randy Lessard, Vice President and General Manager of Nichols Portland, is excited about the economic opportunities the Pump Division brings to southern Maine. "Our innovative products are designed and rigorously tested by our engineering team right here in Maine. Our pumps are built using components that are manufactured at our powdered metal components plant on Congress Street, as well as electronics and machined parts purchased from several other Maine businesses. We are fortunate to be a part of Maine's vibrant business community and look forward to achieving our growth objectives in our new space."

Thomas Houck, CEO and President of Nichols Portland, commented on the opening, "Given Nichols Portland's long history and leading position in the niche pump industry, this new facility will help bolster applications in our existing customer base and we are excited to offer a more holistic solution to our customers."

"We are excited about Nichols Portland's expanded footprint in North America. Nichols Portland is a great example of bringing additional capabilities to the market and to be a solution provider/problem solver for our customers," he concluded.

New 550-ton powder press

Nichols Portland also reported the addition of a new 550-ton Rigid Reflex compacting press at its facility in Portland.

Nichols Portland has added a new Cincinnati Rigid Reflex powder press to its pressing capabilities (Courtesy Cincinnati Incorporated)

The Rigid Reflex press from Cincinnati Incorporated, Harrison, Ohio, USA, is said to be suited to long-run, high-speed production of a range of PM components and can produce parts with up to four lower and two upper levels.

"In a time where organisations are pulling back on investments, Nichols Portland is full steam ahead on our growth activities," stated Stephen Madill, VP Sales & Marketing, Nichols Portland.

www.nicholsportland.com

Pfeiffer Vacuum doubles size of its China facility

Pfeiffer Vacuum GmbH, headquartered in Asslar, Germany, has expanded its facility in Wuxi, China. Reported to be double its original size, Pfeiffer Vacuum states that the new, expanded facility marks a significant milestone in its development in China, allowing the company to better respond to local customers' needs while supporting its strategic growth in the local coating and semiconductor market.

Pfeiffer Vacuum added that since entering the Chinese market in 2007 it has maintained steady growth, employing over 150 in the region. With its recently expanded facility, the company expects to deliver more value to local customers and deepen its commitment to the Chinese market in the future.

"This is part of our new growth strategy which includes a global investment programme of €150 million," stated Hugh Kelly, representative of Pfeiffer Vacuum's management board.

"In addition to providing after-sales service, the bigger facility will now also allow for the production of dry pumps and our new leak detection systems ATC, as well as the assembly of pumping stations. With the introduction of industry-leading technologies and equipment, Pfeiffer Vacuum is better poised to react to the needs of local customers."

www.pfeiffer-vacuum.com

International Powder Metallurgy & Cemented Carbide Exhibition in Shenzhen

The Shenzhen International Powder Metallurgy & Cemented Carbide Exhibition and the Shenzhen International Advanced Ceramics Exhibition (PMCC&AC Expo) is set to take place at the Shenzhen Convention & Exhibition Center, China, from July 1–3, 2020.

Organised by Wise Exhibition (Guangdong) Co., Ltd., the PMCC&AC Expo brings together professionals and representatives from the cemented carbide, Powder Metallurgy and advanced ceramics industries to display the latest process technology and equipment. The three-day event is expected to attract 30,000 industrial and academic representatives to attend the exhibition, with 400 companies exhibiting.

The following technologies and products will feature during the exhibition:

- Powder Metallurgy raw materials
- Cemented carbide raw and auxiliary materials
- Cemented carbide and Powder Metallurgy manufacturing equipment
- Cemented carbide and Powder Metallurgy products
- Detection equipment and technologies
- Advanced ceramic raw materials
- Advanced ceramic equipment
- Advanced ceramic parts/products
- Additive Manufacturing

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

www.pmccexpo.com

Lauffer Pressen to hold second International Technology Forum

Lauffer Pressen, Horb, Germany, will hold its second International Technology Forum, part of its 'Lauffer Technology Days', at its Horb base from April 23–24, 2020. The event features a two-day in-house exhibition for customers and operators of presses and automated production systems, as well as presentations from high-level speakers.

Attendees from the Powder Metallurgy and carbide industries will have the opportunity to view the new Lauffer E-Line powder compacting press, Lauffer's first fully electric press system designed for carbide, ceramic and Powder Metallurgy component producers. Also on display will be new developments within the Lauffer C-Line family, a line of powder compacting systems offering 63–500 tons of press force.

www.lauffer.de

Toyota and BYD to establish joint company for battery electric vehicle R&D

China's BYD Company and Japan's Toyota Motor Corporation have signed an agreement to establish a joint company for research and development in the field of battery electric vehicles (BEVs). The new company, which will design and develop BEVs (including platforms) and related parts, is expected to be established in China in 2020 with equal investment from each company.

BYD manufactures automobiles, battery-powered bicycles, buses, forklifts, rechargeable batteries, trucks and more. On the establishment of the joint venture, BYD's Senior Vice President, Lian Yu-bo, commented, "We aim to combine BYD's strengths in development and competitiveness in the battery electric vehicle market with Toyota's quality and safety technology to provide the best BEV products for the market demand and consumer affection as early as we can."

Shigeki Terashi, Toyota's Executive Vice President, added, "With the same goal to further promote the widespread use of electrified vehicles, we appreciate that BYD and Toyota can become 'teammates', able to put aside our rivalry and collaborate. We hope to further advance and expand both BYD and Toyota from the efforts of the new company with BYD."

Toyota launched its Prius, the world's first mass-produced hybrid electric vehicle (HEV), in 1997, and has since become a pioneer of electrified vehicle development with a focus on HEVs. The company has sold more than 14 million electrified vehicles worldwide and has accumulated extensive knowledge concerning the development, production and sale of both HEVs and their related core components.

In 2008, BYD became the first company to mass produce plug-in hybrid electrified vehicles (PHEVs). Since 2015, BYD's sales of BEVs and PHEVs have been ranked first in the world.

Toyota has made several investments in the Chinese auto market in recent years and is said to be working on developing vehicles which meet Chinese customers' needs through a number of collaborations between Toyota Motor Engineering & Manufacturing (China) Co., Ltd. (TMEC) and the R&D centres established at Chinese joint-venture companies with China FAW Group Corporation (FAW) and Guangzhou Automobile Group Co., Ltd. (GAC).

www.global.toyota
www.byd.com

IMET Alloys announces €10 million investment in aerospace-grade titanium processing

IMET Alloys Europe, Ltd., a UK-based company focused on the processing and supply chain management of titanium and superalloy materials, has announced a €10 million investment to establish Europe's first dedicated aerospace-grade titanium processing facility. The plant will be built and equipped by IMET at Saint Georges-De Mons, near Clermont-Ferrand, France.

IMET, headquartered in Livingston, Scotland, provides users of titanium and superalloys with furnace-ready products to melt ingots which are used in the aerospace, oil and gas, power generation and medical sectors. The new plant will convert titanium waste generated by aircraft manufacturers and their subcontractors into clean, furnace-ready material.

This material will then be fed directly back into titanium melting facilities and is expected to help create a circular economy within Europe's aerospace manufacturing supply chain. Ruaraidh Williamson, Chief Executive Officer of IMET, stated, "We're delighted to be establishing our first dedicated titanium plant and European headquarters in France. The facility will be designed and purpose-built by us to handle titanium alloys of today and tomorrow."

"We will be employing exclusive technologies developed by IMET to cement our position as the processor and supplier of next-generation alloys utilised in the latest energy-efficient engines," he continued. "Our commitment to this project is a vital step for keeping titanium materials in Europe while reducing the carbon footprint of titanium melting activities through the displacement of ore based primary raw materials."

"IMET's unique value proposition is vital to the creation of a European aerospace circular economy, completing the circular flow and efficient use of titanium materials, delivering environmental, climate and socioeconomic benefits ranging from reduced transportation needs to lower raw material imports and a more self-sufficient European titanium supply-chain," he concluded.

IMET operates out of two facilities in Livingston, two in the USA and one in the Czech Republic. Its clients include companies such as General Electric, Rolls-Royce and Safran SA.

IMET Alloys provides furnace-ready titanium and superalloy materials to the aerospace, oil and gas, power generation and medical sectors (Courtesy IMET Alloys)

This new investment follows the signing of a ten-year service agreement with EcoTitanium, France, at the 2019 Paris Air Show. Construction on the new facility in France will commence in July 2020 and the plant is expected to be operational by 2022. IMET also recently invested $3 million in an expansion of its Monroe, USA, facility which will be officially opened later this year.

www.imetalloys.com

Plansee to construct new sintering facility and training centre

Plansee Group, headquartered in Reutte, Austria, is investing in a new sintering facility and has begun construction of a new €6 million training centre.

According to the group, the new sintering facility is the culmination of many years of preparation, including the development of new processes and technologies reported to have been extensively trialled in test facilities. Its engineers are said to have been particularly keen to reduce the volume of raw materials it uses, increase material quality, and reduce sources of errors through automation in order to make production faster and more reliable.

Another focus of the development is said to be to save energy. To achieve this goal, hydrogen used in the sintering equipment at the new facility is to be recycled and the cooling water to be used to heat other parts of the factory.

The ground-breaking ceremony for the new sintering facility took place in September. Although the group has not yet confirmed any further information, Plansee reports that it is investing several tens of millions of euros in the new plant, along with all the associated equipment and new technological developments. Ulrich Lausecker, Plansee's Managing Director, commented, "Construction of our new sintering plant will allow us to elevate our production to a new level of quality and to save energy and material."

New training centre

The new €6 million training centre is located in Breitenwang, Austria. Once completed, the 3,000 m^2 centre will allow up to 240 people to receive training in a variety of metalworking professions.

According to the company, construction is scheduled to take one year, with the centre expected to be operational as of the beginning of the academic year in September 2020. The vocational school at Plansee will also be expanded, with new classrooms and IT rooms being added, as well as laboratories for hydraulics, pneumatics and electrical engineering to accommodate a growing number of students.

"We see a growing need for well-trained specialists, and the construction of our new training workshop sets us up for taking on up to sixty apprentices each year," stated Bernhard Schretter, Member of the Executive Board of the Plansee Group. Currently, forty apprentices are being taken on each year by the company. "We will continue to train apprentices for our own needs in the future," Schretter added.

In addition to job-specific theoretical and practical skills, vocational training at Plansee places great emphasis on personal development, including a range of teamwork and projects. Schretter added, "We have been following a path of combining careers and apprenticeships for decades. Many of our longstanding, seasoned managers started their careers with an apprenticeship at Plansee and Ceratizit."

Plansee and Ceratizit currently offer apprenticeships for metallurgical technicians with cutting technology and mechanical engineering as the primary modules, process technician, materials engineering technician, electrical engineer, chemical laboratory technician, office administrator and information technologist.

www.plansee.com

Miba and Zollern joint venture for engine and industrial bearings

Austria's Miba AG has launched a joint venture with Zollern GmbH & Co. KG, headquartered in Laucherthal, Germany, to develop and expand both companies' range of engine and industrial bearings.

Miba will bring its five engine bearing plants to the partnership, which currently generates around 20% of Miba's earnings, with Zollern adding two industrial bearing plants and one engine bearing plant.

The goal of the joint venture is said to be to combine the strengths of Miba and Zollern in the bearing business, and thereby better position them for global competition. For Miba, the step mainly serves to expand its industrial bearing business, which has grown from four to six production facilities in Germany, the United States and Brazil. The engine bearing segment will also have an additional plant in Germany.

By pooling their expertise in research and development, the companies also stated that they can make an important contribution to the development of new solutions in decarbonisation and renewable energy through new bearing technologies for wind power turbines.

The joint venture is headed by Deputy CEO of Miba AG and CEO of the Miba Bearing Group, Dr Wolfgang Litzlbauer. Miba holds 74.9% of the joint venture, with the remaining 25.1% held by Zollern.

Miba's existing four industrial bearing plants do not form part of the joint venture, and other business areas at Miba and Zollern will reportedly be unaffected.

www.miba.com.
www.zollern.com

AAM opens new manufacturing facility near Barcelona

AAM has announced the opening of its new manufacturing facility near Barcelona (Courtesy American Axle & Manufacturing, Inc.)

American Axle & Manufacturing, Inc. (AAM), Detroit, Michigan, USA, has announced the official opening of its new 15,600 m^2 manufacturing facility, located 20 km south west of Barcelona in Viladecans, Spain. The new facility is said to offer a lean, efficient production layout and optimised materials flow.

According to the company, the new manufacturing facility consolidates two smaller facilities in nearby Gavà, and at full capacity will employ nearly 300. It is expected to support demand and growth from new and current European customers including Renault, BMW, Daimler, Porsche, Audi and Ford.

AAM Barcelona produces a range of vibration control and damper products including PV bonded dampers, press-in compression dampers, isolation pulleys, in-mould bonded dampers and damped gears. The company will produce damped gears for Ford, BMW, Miba and PSA; PV bonded dampers for Audi, Mercedes and FCA; isolation pulleys for Renault; and in-mould bonded dampers for Mercedes, Ford and Porsche.

"AAM's new Barcelona Manufacturing Facility is a key part of our continued mission to diversify and expand our global customer base and product mix," stated David C Dauch, AAM Chairman and Chief Executive Officer. "European automakers are continuing to downsize engines and AAM's segment-leading products support this mission with technology that helps reduce noise and vibrations in the vehicle."

Greg Deveson, President, AAM Driveline, commented, "AAM is a leader in this segment having pioneered the isolation pulley, many types of viscous dampers and damped gears. As production of downsized engines and hybrid applications increases, AAM will support our customers with industry-leading technologies that meet and exceed performance and quality expectations."

www.aam.com

Bodycote opens new heat treatment facility in Prague

Bodycote, a global provider of heat treatment and specialist thermal processing services headquartered in Macclesfield, Cheshire, UK, has officially opened its new heat treatment facility in Prague, Czech Republic. The new heat treatment centre is now fully operational and providing a range of heat treatment services, having been established to support the automotive and general industrial markets in the region.

Bodycote has operated a heat treatment plant in Prague since the early 1990s, but due to growth and demand, reports that it outgrew its premises. The new plant is said to have been purpose built to replace the original Prague facility, with additional space on-site for anticipated growth. Speaking at the facility's opening, Paul Clough, President of Bodycote's Classical Heat Treatment division for Northern Europe & Asia, stated, "Bodycote is proud to be opening our newest facility in Prague, where we can be close to our customers and grow to meet their future demand."

Roman Poslusny, Vice President of Operations of Central Eastern Europe for Bodycote's Classical Heat Treatment division, added, "The Czech Republic is an excellent place for Bodycote to invest in order to support our customers' supply chains locally. This expansion helps to demonstrate our commitment to our Eastern European customers by providing the best possible service."

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

www.bodycote.com

Abbott appoints Jacobs as Marketing Manager

Abbott Furnace Company, St. Marys, Pennsylvania, USA, has appointed Mike Jacobs as its new Marketing Manager. Jacobs brings almost fifteen years of industry experience gained from his previous positions at Seco/Warwick, where most recently he managed its Controlled Atmosphere Brazing (CAB) business and Roller Hearth product line. The company states that Jacobs' extensive experience with high-volume production furnaces as well as low volume batch furnaces gives him a unique perspective on the aluminium brazing and heat treating market.

Jacobs has a Bachelor of Science degree from Edinboro University and has previous experience in the plastic injection moulding industry. He joined Abbott Furnace Company in September 2019.

www.abbottfurnaceco.com

Euro PM2019: EPMA Fellowship, Distinguished Service Awards and Thesis Competition winner announced

EPMA President Ralf Carlström presented the awards. Top left: EPMA PM Thesis Competition 2019 winner - Doctorate/PHD Category - Dr Chu Lun Alex Leung (centre) with Euro PM2019 TPC Co-Chair Prof Jie Zhou. Top right: EPMA Distinguished Service Award 2019 Winner, Dr-Ing Ingo Cremer. Bottom left: EPMA Fellowship Award Winner 2019 - Prof Francisco Castro. Bottom right: EPMA Fellowship Award Winner 2019 - Prof Dr-Ing Bernd Kieback (Courtesy EPMA)

The European Powder Metallurgy Association (EPMA) announced the recipients of its annual Fellowship Award, Distinguished Service Award and Thesis Competition at the Euro PM2019 Congress & Exhibition, in Maastricht, the Netherlands, October 13-16, 2019.

The EPMA Board and Council's Fellowship Award recognises individuals in the scientific and/or academic community for significant contributions to the development of the PM industry. The two recipients of the 2019 Fellowship Awards were Professor Francisco Castro and Professor Dr-Ing Bernd Kieback.

Before becoming a PM industry consultant, Professor Castro was a Principal Senior Researcher at Spain's CEIT, being the director of the Materials and Manufacturing Division. Professor Kieback is Chair Powder Metallurgy & Composite Materials, Technische Universität Dresden, Institute of Materials Science, and Fraunhofer Institute for Manufacturing and Advanced Materials IFAM Dresden.

The 2019 Distinguished Service Award was presented to Dr-Ing Ingo Cremer, CEO, CREMER Thermoprozessanlagen GmbH, Düren, Germany.

The annual EPMA Thesis Competition award was presented to Dr Chu Lun Alex Leung, from the University of Manchester, UK, for his paper on the 'X-ray Imaging of Powder Consolidation During Laser Additive Manufacturing'.

Euro PM2019 covered all aspects of Powder Metallurgy, and featured a congress programme of over 300 technical papers, in addition to the parallel Euro PM Exhibition, featuring more than 100 exhibiting companies.

www.europm2019.com

Project on modelling of springback after cold die compaction

A new collaborative project has been announced that aims to establish a model for prediction of springback following cold die compaction in the Powder Metallurgy process. To be coordinated by OCSynergies, along with the University of Trento and the Polytechnical Institute of Grenoble, the project is expected to last twelve months.

The Modelling of Springback after Cold Die Compaction (MoSC) project aims to investigate the expansion of a green part that occurs during its ejection from the die cavity, referred to as springback, both experimentally and theoretically. OCSynergies states that one of the objectives of the project is the demonstration that springback may be accurately predicted.

It is suggested that two different powders will be used for the purpose of the project: an iron-based alloy and a WC-Co alloy. A model based on the stress/strain relationships in non-linear and anisotropic elasticity will be developed for a simple geometry and validated through experiments using an industrial hydraulic press.

The MoSC project intends to be the starting point for further investigations in this field to be developed with the project partners.

The total budget of the project is reported to be €32,000, with fees shared by a minimum of four funding participants. Those interested in joining the MoSC project are invited to contact Dr Olivier Coube olivier.coube@ocssynergies.com.

www.ocsynergies.com

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Rotary Type Powder Forming Press

Multi-function Processing Machine

YASA closes £18 million funding round, prepares for rapid growth

YASA, Oxford, UK, a manufacturer of axial-flux electric motors and controllers for hybrid and pure electric vehicles has announced the closing of an £18 million funding round. The new funding is expected to enable the company to scale to meet rapidly growing customer demand from the automotive and aerospace sectors.

YASA's axial-flux electric motors contain a number of pressed stator cores manufactured from soft magnetic composite iron powder, and are said to offer best-in-class power and torque densities. This gives manufacturers the opportunity to improve performance whilst reducing weight.

Existing investors Parkwalk Advisors and Universal Partners were joined in this latest funding round by Oxford Sciences Innovation (OSI) and Inovia Capital. This news follows the announcement in May 2019 that Ferrari's first hybrid production series supercar, the SF90 Stradale, is powered by a custom YASA axial-flux electric motor.

The YASA motor in the SF90 Stradale is highly compact with a power density of 14 kW/kg, allowing Ferrari to deliver a high level of vehicle performance whilst reducing vehicle weight. The motors will be manufactured in YASA's production facility in Oxford, UK.

Ferrari's SF90 Stradale is powered by a custom YASA axial-flux electric motor (Courtesy Ferrari)

Speaking of the new funding round, Charles Conn, CEO at OSI, stated, "We have been tracking YASA's progress for a number of years and are pleased to have the opportunity to invest in one of the UK's most exciting high-growth technology companies that is well-positioned to take advantage of the rapid move to electrification in both automotive and aerospace sectors."

Patrick Pichette, General Partner at Inovia Capital, added, "YASA exemplifies what we look for in our portfolio companies – a company with high-growth potential and a team that's passionate about building a better world through the discovery and application of innovative technology. YASA's electric motors and controllers are opening up entirely new opportunities for vehicle manufacturers, enabling them to create exciting electric driving experiences while reducing the impact on the environment."

Dr Chris Harris, YASA's CEO, commented, "This funding round is helping prepare the company to meet the rapidly increasing volume of demand for our electric motors and controllers from our automotive customers. We're pleased to welcome OSI and Inovia on board as investors – both share our long-term vision for the company and bring tremendous operational experience that will help us realise our full potential."

www.yasa.com

Hyundai Motor to invest $34.6 billion in auto and mobility technologies

Hyundai Motor Group, Seoul, South Korea, has revealed plans to invest ₩41 trillion ($34.6 billion) in mobility and auto technologies by 2025, according to *Automotive News*. The plan is reported to include electric vehicles, ride-sharing technology, autonomous and connected vehicles.

The South Korean government also revealed that it will invest further in autonomous vehicle technology, while South Korean companies overall are expected to invest $50 billion over the next decade in future transportation technologies. The self-driving vehicle market is expected to make up much of these investments, with South Korea's President Moon Jae-in stating in a speech at Hyundai Motor's research facility that this market could "revitalise the economy and create new jobs."

A total investment of $1.4 billion is planned by the government between 2021–2027. Hyundai Motor is expected to launch fully autonomous cars for fleet customers in 2024, and passenger cars for the general public in 2027.

www.hyundaimotorgroup.com

Air Products begins construction of new global headquarters

Air Products recently held a ceremonial groundbreaking for its new global headquarters in Lehigh Valley, Pennsylvania, USA. More than two-hundred guests were in attendance at the event, including both Air Products personnel as well as state officials and dignitaries.

The company has been in operation for over seventy-five years, providing gases and related equipment to a number of industries, including metals, manufacturing, refining, chemicals, electronics, and food and beverage. It is also a leading supplier of liquefied natural gas process technology and equipment.

Air Products employs around 16,000 staff globally, and in 2018 reported fiscal sales of $8.9 billion from its operations in fifty countries. It has a current market capitalisation of approximately $50 billion.

The company's new headquarters is located just over one mile from its existing location and occupies fifty-acres. Occupancy is targeted for Summer 2021, when the facility will become the base for approximately 2,000 Air Products employees, with capacity for growth. The site will include new administration offices and a research and development facility. In addition to a previously announced agreement for a portion of the site, the company has made the balance of its existing location available to the real estate market.

Seifi Ghasemi, Chairman, President and CEO of Air Products, stated during the groundbreaking, "We need a headquarters that represents who we are as a world-leading company. We want to create modern office and R&D facilities that are energising, collaborative and inclusive. When you see the new global headquarters renderings, without any doubt, the new office space and world-class R&D facility will be representative of who we are and what we stand for."

"This new headquarters will exemplify our '4S' culture and reflect the safety, speed, simplicity and self-confidence that have driven our success and will continue to do so," he continued. "We will also emphasise a fifth 'S' with these new facilities – sustainability. Sustainability is at the heart of what we do as a business, every day around the world. That's important to our customers, our partners, and our talented and committed employees."

Sustainability features at the new location include a much smaller building footprint, highly energy-efficient buildings, solar panels, green roofs and a hydrogen vehicle fuelling station.

www.airproducts.com

Umicore and IndustriALL renew sustainable development agreement

Global materials technology and recycling group Umicore, headquartered in Brussels, Belgium, has renewed its Global Framework Agreement on Sustainable Development for four years with IndustriALL Global Union, an organisation representing 50 million workers in the mining, energy and manufacturing sectors.

The agreement is said to reaffirm Umicore's commitment to sustainable development and its pursuit of economic, environmental and social objectives. It covers human rights (including collective bargaining and equal opportunities), safe and healthy working conditions, environmental and supply chain matters, and digital transformation.

The global framework agreement was first signed in 2007 and renewed in 2011 and 2015. This will be its third renewal. The latest agreement reportedly contains a number of additions and improvements, including a new section on violence and harassment at work, in line with the newly adopted ILO Convention 190, and stronger language on suppliers and subcontractors.

Marc Grynberg, Umicore CEO commented, "This agreement reaffirms our commitment towards sustainability in which the engagement of all Umicore employees is vital. The dialogue with IndustriALL plays an important role in our quest to be a front-runner in all aspects of sustainability, particularly along the supply chain of critical materials."

Valter Sanches, General Secretary of IndustriALL Global Union, stated, "IndustriALL Global Union is pleased with the long-standing partnership with Umicore in the context of this global framework agreement. We look forward to continuing our joint work with a new motivation over the new improvements in the agreement, especially the provision on due diligence in the supply chain."

www.umicore.com

PMAI announces dates for its PM2020 Conference in Mumbai

The Powder Metallurgy Association of India (PMAI) has announced dates for its International Conference on Powder Metallurgy and Particulate Materials & Exhibition 2020 (PM20).

The event will take place from February 19-21, 2020 at The Lalit Mumbai, Sahar Airport Road, Andheri East, Mumbai, India, and will once again combine a technical programme and an international trade exhibition. PM20 will also include the 46th Annual Technical Meeting of PMAI.

www.pmai.in

Ipsen USA expands its aftermarket service by employing five regional sales engineers

Ipsen USA, Cherry Valley, Illinois, USA, has expanded its aftermarket service coverage across the US and Canada by hiring five regional sales engineers (RSEs) to assist customers with replacement parts, retrofits, upgrades, service and technical support for any brand of atmosphere or vacuum heat-treating system.

According to the company, the RSEs will fill a crucial role by creating a more efficient system for managing customer needs and streamlining the process between new equipment sales, aftermarket service, and field support. The RSEs reportedly offer a range of experience in engineering, machine repair and metallurgical processes.

They are supervised by Matt Clinite, Ipsen Customer Service Sales Manager, who stated, "Our team is here to identify risk points with our customers' equipment. Our goal is to help our customers better prepare for maintenance planning and experience maximum furnace up-time and reliability."

www.ipsenusa.com

Ceratizit holds inauguration ceremony for site expansion in India

Ceratizit Group, headquartered in Mamer, Luxembourg, recently held an inauguration ceremony for its site expansion in Bengaluru, India. Ceratizit develops and manufactures specialised carbide cutting tools, inserts and rods made of hard materials, as well as wear parts.

The ceremony was attended by the Ambassador of the Grand Duchy of Luxembourg to India, H E Jean Claude Kugener, as well as members of the Executive Board; Thierry Wolter, Andreas Lackner and Andreas Schwenninger together with Gerhard Bailom, Ashwani Sareen and Kumar, Anil.

Ceratizit develops and produces sophisticated hard material cutting and wear protection solutions, including cutting tools, indexable inserts and carbide rods, and new types of carbide and cermet grades. The group has over 9,000 employees at more than thirty global production sites and operates a sales network of over seventy branch offices.

www.ceratizit.com

Gasbarre works with Thermal Technic Furnace Solutions representative to expand presence in Mexico

Gasbarre Thermal Processing Systems, based in St. Marys, Pennsylvania, USA, part of Gasbarre Products Inc., has announced that it will work with Humberto Bastidas of Thermal Technic Furnace Solutions to further promote the company in Mexico.

Thermal Technic Furnace Solutions represents numerous American manufacturers in Mexico, and will aid Gasberre in launching a Spanish-language version of the Gasbarre.com website, along with expanding marketing efforts in the region.

Bastidas and the Thermal Technic Furnace Solutions team are said to have many years of experience in the the heat treating field, and it is believed that current and future customers in the Mexican region will benefit from having a local, Spanish speaking representative.

www.gasbarre.com/thermal-processing-systems
www.thermaltechnic.com

Submitting news..

To submit news to *PM Review* please contact Paul Whittaker: paul@inovar-communications.com

Construction begins on GF Machining Solutions' new Canadian HQ

GF Machining Solutions, along with sister division GF Piping Systems, has begun construction of a new joint regional headquarters in Vaughan, Ontario, Canada. The companies broke ground on the new 6,200 m^2 (67,000 ft^2) facility in late October 2019.

The new Canadian headquarters will feature a 450 m^2 (4,800 ft^2) demonstration centre, staffed by a full sales and service support team. Also serving as a distribution centre, the facility will streamline the sales and acquisition process for customers, as well as helping to shorten delivery times.

"Investing domestically in Canada and improving upon our local services will further enhance both GF Machining Solutions' and GF Piping Systems' abilities to serve the Canadian market," stated Philipp Hauser, President – Head of Market Region North and Central America for GF Machining Solutions. "Manufacturers in this region have come to know and understand the quality, strength and reliability of the GF brand, and this new facility will provide easy, localised access to our full range of manufacturing technologies."

GF Machining Solutions, headquartered in Switzerland, is a global provider of machine tools, solutions and services to manufacturers of moulds and tooling, and of precision-machined components. The company's portfolio includes Electrical Discharge Machining (EDM) solutions, three- and five-axis milling machines and spindles, laser texturing machines, Additive Manufacturing machines and machines for laser micro-machining, to solutions for tooling, automation, software and digitalisation.

www.gfms.com

Breaking ground on the new Canadian HQ. From left to right: Heather Newman, Operations and Inside Sales Manager (GF Piping Systems), John Giroux, Managing Director (GF Piping Systems), Mark Sanhamel, Director of Operations (GF Machining Solutions), Sean Smith, Sales Manager – Canada (GF Machining Solutions) and Philipp Hauser, President – Head of Market Region North and Central America (GF Machining Solutions)

MPIF's new Standard Test Methods for Metal Powders and PM Products published

The Metal Powder Industries Federation (MPIF) has announced the publication of the 2019 edition of its Standard Test Methods for Metal Powders and Powder Metallurgy Products. The most current versions of these standards, which are used in the manufacture of both metal powders and PM components, are often required by quality assurance programmes in order to maintain full compliance.

This new volume is said to contain forty-five standards covering terminology and recommended methods of test for metal powders, PM and MIM parts, metallic filters, and Powder Metallurgy equipment.

New to the 2019 edition are:

- MPIF Std. 70: Sample Preparation of Ferrous Powder Metallurgy (PM) Materials for Cross-Sectional Metallographic Evaluation
- MPIF Std. 71: Sample Preparation of Copper-Based Powder Metallurgy (PM) Materials for Cross-Sectional Metallographic Evaluation
- MPIF Std. 72: Sample Preparation of Aluminum Powder Metallurgy (PM) Materials for Cross-Sectional Metallographic Evaluation

The new standard is available to purchase via the MPIF's publications page, and can be bought at a discounted rate by MPIF and APMI members.

www.mpif.org

Isostatic Toll Services expands capabilities with new HIP system

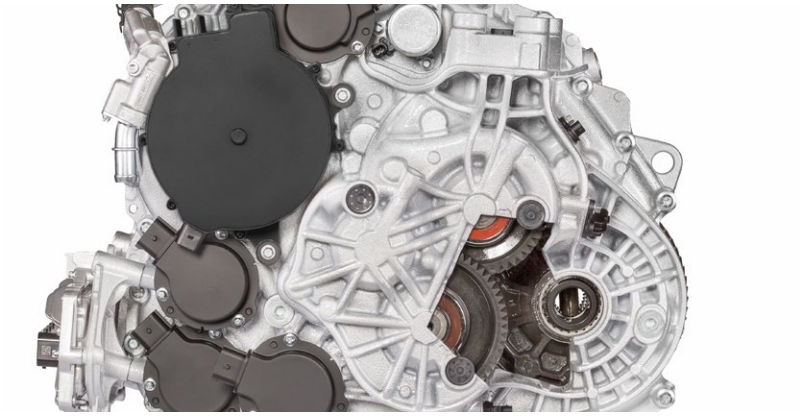
Isostatic Toll Services (ITS) headquartered in Olive Branch, Mississippi, USA, reports that it has expanded its Hot Isostatic Pressing (HIP) capabilities up to 30,000 psi with the addition of a new HIP system to its range.

According to the company, the new system can fulfil the higher pressure requirements necessary for aerospace and orthopaedic parts and additively manufactured designs. This is the second recent range expansion for the company, which installed a new HIP system in 2018, providing capabilities of up to 20,000 psi.

The company recently passed its NADCAP AC7102/6 audit re-certification for Hot Isostatic Pressing and is certified to ISO 9001 (Aerospace), ISO AS9100C (Aerospace) and ISO 13485 (Medical). It is also reported to have passed exhaustive onsite quality audits by MTU Aero Engines and Rolls Royce.

www.isostatictollservices.com

Magna wins largest contract for transmission technologies in its history



Magna is to build dual-clutch transmissions, including hybrid variants, for the BMW Group (Courtesy Magna)

Germany's BMW Group has awarded Magna International the largest production order for transmission technologies in the automotive supplier's history. The multi-year contract is reported to include all front-wheel drive dual-clutch transmissions, including hybrid transmission variants, and will be used in more than 170 different vehicle applications.

The new hybrid solution by Magna is said to have no impact on the overall package size of the transmission, which provides manufacturing flexibility to BMW. The hybrid variants also use a compact, 48V high-RPM electric motor within the transmission housing, providing innovative driving features while further improving fuel efficiency.

"This new award is another result of Magna's commitment to delivering high-quality, flexible and innovative transmissions," stated Tom Rucker, President of Magna Powertrain. "Our scalable dual-clutch transmissions enhance drivability while simultaneously providing optimal levels of efficiency, which makes our product a perfect match for BMW."

The transmissions will be built at Magna facilities in Neuenstein, Germany, and Kechnec, Slovakia.

www.magna.com

Hot Isostatic Pressing seminar heads to Oslo

The European Powder Metallurgy Association (EPMA) will hold its Hot Isostatic Pressing (HIP) seminar in Oslo, Norway, on February 25–26, 2020. The focus of the 2020 seminar will be 'The use of HIP to improve safety and innovation offshore' in the oil and gas industry.

HIP has been used for many years in the oil and gas industry to produce near net-shape components from metal powders and to close porosity in cast products. More recently, Additive Manufacturing has also entered this space; HIP can be used with AM to ensure material performance for the most critical applications.

The 2020 HIP seminar will be hosted at Energy Valley (Research Center) and features presentations from a number of industry figures, as well as a site visit to DNV-GL and the opportunity to network and discuss the future of the HIP market. It is expected to be of interest both to end-users and designers, as well as to technical and managerial personnel in the HIP industry.

Registration for the seminar will close on February 5, 2020.

www.seminars.epma.com

Marelli to close four production facilities in Japan

Global automotive parts supplier Marelli Corporation, formed following the merger of Japan's Calsonic Kansei Corporation and Italy's Magneti Marelli, has announced plans to reorganise its production bases in Japan, which will result in the company ceasing production within its Calsonic Kansei Tochigi Corporation Tochigi Plant and Sano Plant District 1; Calsonic Kansei Utsunomiya Corporation; and Calsonic Kansei Yamagata Corporation operations.

On September 9, 2019, Calsonic Kansei Corporation announced that it would change its name to 'Marelli Corporation', while its Italian business, Magneti Marelli S.p.A, will be renamed 'Marelli Europe S.p.A' as of October. Following this, the names of its major affiliate companies will also be changed to Marelli. The changes reflect the company's €6.2 billion takeover of Magneti Marelli earlier this year, creating the world's seventh-largest global independent automotive supplier.

The closures are said to form part of the group's ongoing strategy, expected to ensure its operations are structured in a way that can best respond to significant changes within the global and domestic automotive industry. Following a review, the company stated that there are no viable alternatives to these plans.

Marelli added that it is working to strengthen its position so that it can compete as a global Tier 1 supplier. To do this, it is focused on growing its business through customer and product diversification, cost leadership, the development of a world-class product portfolio and targeted technology leadership.

The company plans to cease operations at Calsonic Kansei Tochigi Corporation Tochigi Plant and Sano Plant District 1, which among other parts produce heat exchangers and climate control systems, at the end of February 2020. Calsonic Kansei Utsunomiya Corporation, which produces air-conditioning compressors, will follow at the end of September 2020 and Calsonic Kansei Yamagata Corporation, also a producer of air-conditioning compressors, at the end of October 2020.

It was stated that Marelli will transfer, as appropriate, production at these plants to other plants in the group and provide as much support as possible to the plant employees, enabling them to be moved to group companies in principal. In total, the affected plants employ 644 staff.

www.calsonickansei.co.jp

Submitting news..

To submit news to *PM Review* please contact Paul Whittaker: paul@inovar-communications.com

MUT Advanced Heating celebrates its 25th anniversary

MUT Advanced Heating GmbH, headquartered in Jena, Germany, is celebrating its 25th anniversary since it was founded by Heinz-Jürgen Blüm as the MUT company in September 1994. Initially, the company focused on microwave environmental technology before shifting focus to thermal processing plants. It was rebranded as MUT Advanced Heating GmbH in 2003, and has since concentrated on the development of the engineering and production of customised high-temperature furnace technology, both with defined atmospheres and under a vacuum.

MUT believes that its consistent success is due to the systematic implementation of customised approaches to solutions in order to meet higher efficiency requirements and the associated increasing degree of automation in thermal installations. The company's certifications (HPO authorisation, welding fabricator certification) for manufacturing pressure vessels enable it to define the optimal plant selection with its end customers, and guarantee performance on the basis of certified processes.

MUT states that its innovative approaches to thermal process technology are implemented in system solutions in various material sectors, such as ceramics and Powder Metallurgy. The company added that there is continuous interest in the ISO furnace series developed by Blüm.

Due to advancing developments in the fields of materials, energy engineering, and production and process technology, the company recently introduced a new range of AM heat treatment products specifically to meet the demands of the new Additive Manufacturing techniques.

In 2006, together with Element 22 GmbH, Kiel, Germany, MUT founded a joint venture company specifically for the growing titanium technology sector. The TiGen (Titanium Generation GmbH) company is jointly led by H J Blüm and M Scharvogel, CEO of Element 22 GmbH, and specialises in heat treatment and sintering plants for titanium materials and other reactive metals that have been produced by MIM, AM or other forming processes.

"We would like to give a hearty thank you to all our customers, partners, suppliers and employees for the trust and loyalty they have shown to us over past years," the company stated in an anniversary statement. "The entire MUT team is looking forward to a continuation of such reliable and successful cooperation."

www.mut-jena.de

Magna receives grant to develop high-performance, low-cost electric motor

Magna International of America, Inc., based in Troy, Michigan, USA, has been awarded a grant by the U.S. Department of Energy (DoE) for a collaborative project with the Illinois Institute of Technology and University of Wisconsin-Madison. The project aims to develop and 'auto-qualify' advanced electric motor technologies for next-generation vehicle propulsion systems.

As part of the project, Magna will collaborate with its partners to apply its powertrain, electronics and full-vehicle expertise to deliver an automotive-grade, high-performance electric motor that aims to achieve increased power density and reduced cost compared to current e-motors.

The objective is said to be to develop an electric motor that is half the cost and eight times the power density, while delivering 125 kW of peak power. The reduction in cost is achieved by eliminating the use of rare-earth permanent magnets, which make up a significant portion of electric-motor cost.

The project will reportedly integrate the electric motor technologies with a transmission and inverter as part of an overall e-drive system. Magna states that the project scope includes the development and use of innovative materials, cooling technologies, winding technologies, simulation models, and control and optimisation techniques. The developed electric motor technologies will be presented to the DoE for evaluation in 2021.

The high-performance electric motor aims to achieve increased power density and reduced cost (Courtesy Magna)

Swamy Kotagiri, Chief Technology Officer, Magna, commented, "Magna's mission is to make the impossible possible by solving some of the auto industry's most complex problems. Reducing dependency on rare-earth magnets solves two key issues for accelerating access to electrification – supply chain sourcing and cost."

www.magna.com
www.energy.gov

Gammatec Engineering receives Fachmetall PM Qualification Award 2019

Gammatec Engineering GmbH, Radevormwald, Germany, has received the Fachmetall PM Qualification Award 2019 for outstanding services to the Powder Metallurgy industry. Dr Georg Schlieper, General Manager of Gammatec, was presented with the award by Holger Davin and Dr Evelyne Gonia of Fachmetall GmbH, Radevormwald, Germany.

Dr Schlieper has served the PM industry for the majority of his professional life; starting as an engineer, he worked in R&D for high-strength sintered steels, soft magnetic PM materials and the emerging Metal Injection Moulding (MIM) technology. He is credited with the design and launch of the Gamma Densomat, a non-destructive measuring device for the sectional density of metallic and ceramic components.

In 2012, Dr Schlieper founded Gammatec Engineering GmbH, marketing the Gamma Densomat as well as products for industrial furnaces and other high-temperature applications, in molybdenum, tungsten, tantalum and engineering ceramics. Additionally, he regularly reports on company visits, technical conferences and trade exhibitions in *Powder Metallurgy Review, Powder Injection Moulding International* and *Metal AM* magazines.

Fachmetall GmbH is a metallurgical laboratory specialising in investigations of Powder Metallurgy and wrought materials. Its annual 'PM Qualification Award' and the 'QM Context Award' aim to promote companies for their outstanding Powder Metallurgy and quality management activities.

www.gammatec.com
www.fachmetall.de

From left to right: Dr Georg Schlieper with Dr Evelyne Gonia and Holger Davin of Fachmetall GmbH (Courtesy Fachmetall GmbH)

EPMA issues Call for Papers for Euro PM2020

The European Powder Metallurgy Association (EPMA) has issued a Call for Papers for its Euro PM2020 Congress & Exhibition, which will take place in Lisbon, Portugal, October 4–7, 2020. Abstract submissions are invited for presentation in the technical programme, and will reportedly be allocated to either oral or poster sessions by the Technical Programme Committee (TPC) based on authors' wishes, evaluation and the limits of the time schedule.

Each oral session on the programme will contain four presentations, with twenty-minute slots for each paper, including discussion time. Poster presentations will be placed in allocated topic zones and will be displayed for the duration of the four-day event.

The EPMA has confirmed that Euro PM2020 will take place from October 4–7 in Lisbon, Portugal (Courtesy EPMA)

Abstracts for Euro PM2020 are invited on the following topics:

- Additive Manufacturing
- Functional materials, PM magnetic materials, porous materials
- Hardmetals, hard materials, cermets and diamond tooling
- Hot Isostatic Pressing
- PM Applications, materials and processes
- Powder Injection Moulding
- Modelling and simulation
- Non-destructive testing,
- Powder manufacturing and processing
- Powder pressing, secondary and finishing options
- Sintering

Authors are invited to submit their abstracts using the EPMA's online submission form before the deadline of January 22, 2020. Further information is available via the organiser's website.

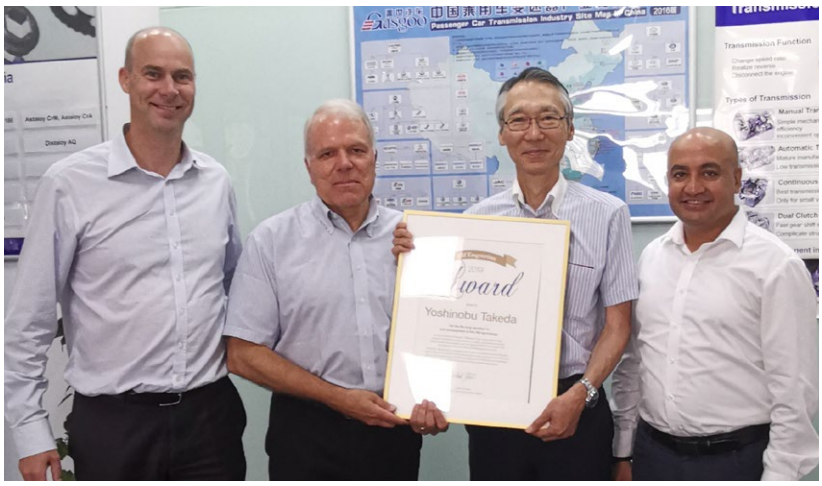
www.europm2020.com

Yoshinobu Takeda receives the 2019 Ulf Engström Award

This year's Ulf Engström Award was presented to Yoshinobu Takeda, Technical Support Engineer at Höganäs in Japan. The annual award is given to an employee of Höganäs who is said to have laid ground for a commercially successful development of the PM industry. The jury cited Yoshinibu's "life-long devotion to and development of PM technology" in their motivation.

The award was presented to Takeda during a ceremony at Höganäs' tech centre in Shanghai, China. "I'm very surprised to have such an honourable award and I am happy to be seen as a person who contributed to Höganäs," stated Takeda.

"Reviewing my eighteen years in Höganäs, this award brings not only a feeling of surprise or happiness; it is much more than that. I recognise that I am a lucky person, and have been given many excellent opportunities. I hope the award will inspire colleagues to work hard for more business opportunities for Höganäs and expand the market, not only for Höganäs, but for PM as a technology."



From left to right: Mark Braithwaite, President Continent APAC, Carl Eklund, President Höganäs Japan, Yoshinobu Takeda, Technical Support Engineer at Höganäs Japan, Shashi Shukla, President Product Area Electro & Mechanical Technologies (Courtesy Höganäs)

During his career, Takeda has contributed to building Höganäs' technical support function in Japan, participated in several global development projects, and developed the company's local Metallography schools.

"I have known Takeda-san for more than thirty years and think he really deserves this award for his outstanding support to the PM industry, not only in Japan but worldwide," added Ulf Engström.

Carl Eklund, who heads up the Höganäs team in Japan, presented the award to Takeda. "What is most remarkable about Takeda-san is that he is always willing to learn and explore new technologies. As of late, he has shown a keen interest to promote 3D printing. He is a true believer in the many opportunities for metal powders, promoting them as smart solutions and sustainable technology. He is a true role model, Mr PM."

www.hoganas.com

General Carbide highlights use of Sinter-HIP in part production

General Carbide, headquartered in Greensburg, Pennsylvania, USA, recently discussed its use of Hot Isostatic Pressing (HIP) in the production of cemented carbide finished products, in a post on its blog. Tungsten carbide graded powder is pressed into shape and consolidated in a process called Sinter-HIP, explained General Carbide.

This thermal consolidation method involves the simultaneous application of high heat and pressure, resulting in a product that is said to contain little or no porosity and is as close as possible to full theoretical density. "HIP produces a finished product that offers the highest level of reliability," the company states. "At General Carbide, we guarantee sinter-HIP on all parts processed through our furnaces to ensure superior metallurgical quality."

Subjecting preforms to sinter-HIPing is also reported to improve nominal transverse rupture strength, ranging from 400,000–560,000 psi. The resulting parts and components are said to have little or no porosity and offer superior reliability for applications in automotive, aerospace, heavy equipment, general industry and the oil & gas sector.

General Carbide produces a wide range of products, from powder to finished components (Courtesy General Carbide)

www.generalcarbide.com

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EPMA Club Project to look at mechanical behaviour and microstructure

A European Powder Metallurgy Association (EPMA) Club Project, focusing on the analysis of the mechanical behaviour and the evolution of microstructure in Powder Metallurgy materials, has been proposed by Spain's IMDEA Materials Institute. The initial Club Project will involve an in-depth study of the mechanical properties and damage prediction of one selected material. The material is yet to be defined, but initial proposals are a stainless steel, such as 316L, or a superalloy such as Inconel. Under the project, PM samples would be compared against samples produced by different manufacturing techniques, such as press & sinter Powder Metallurgy, Additive Manufacturing, Hot Isostatic Pressing (HIP) or Metal Injection Moulding (MIM).

According to the EPMA, the study will cover two different aspects of PM material microstructures. Firstly, mechanical and microstructural behaviour will be studied by means of standard tensile samples as well through special 'in-situ' micro tensile samples machined from blanks produced by the different PM techniques. In the case of AM, the tensile specimens will be obtained in the direction of the build and the perpendicular direction.

Secondly, damage analysis and damage prediction in samples will be obtained by the different methods. Damage will be investigated under tensile stresses at room temperature. The damage will be evaluated as a function of the plastic strain, estimated by digital image correlation, and these data will serve as inputs for the development of a continuum numerical modelling, which could later be used as a predictive tool.

www.epma.com

IOM³ seeks 2020 nominations

The UK's Institute of Materials, Minerals and Mining (IOM³) is seeking nominations for its 2020 awards. Of particular interest to the Powder Metallurgy sector is the institute's Ivor Jenkins Award, presented annually to individuals in recognition of a significant contribution that has enhanced the scientific, industrial or technological understanding of materials processing or component production using Powder Metallurgy and particulate materials.

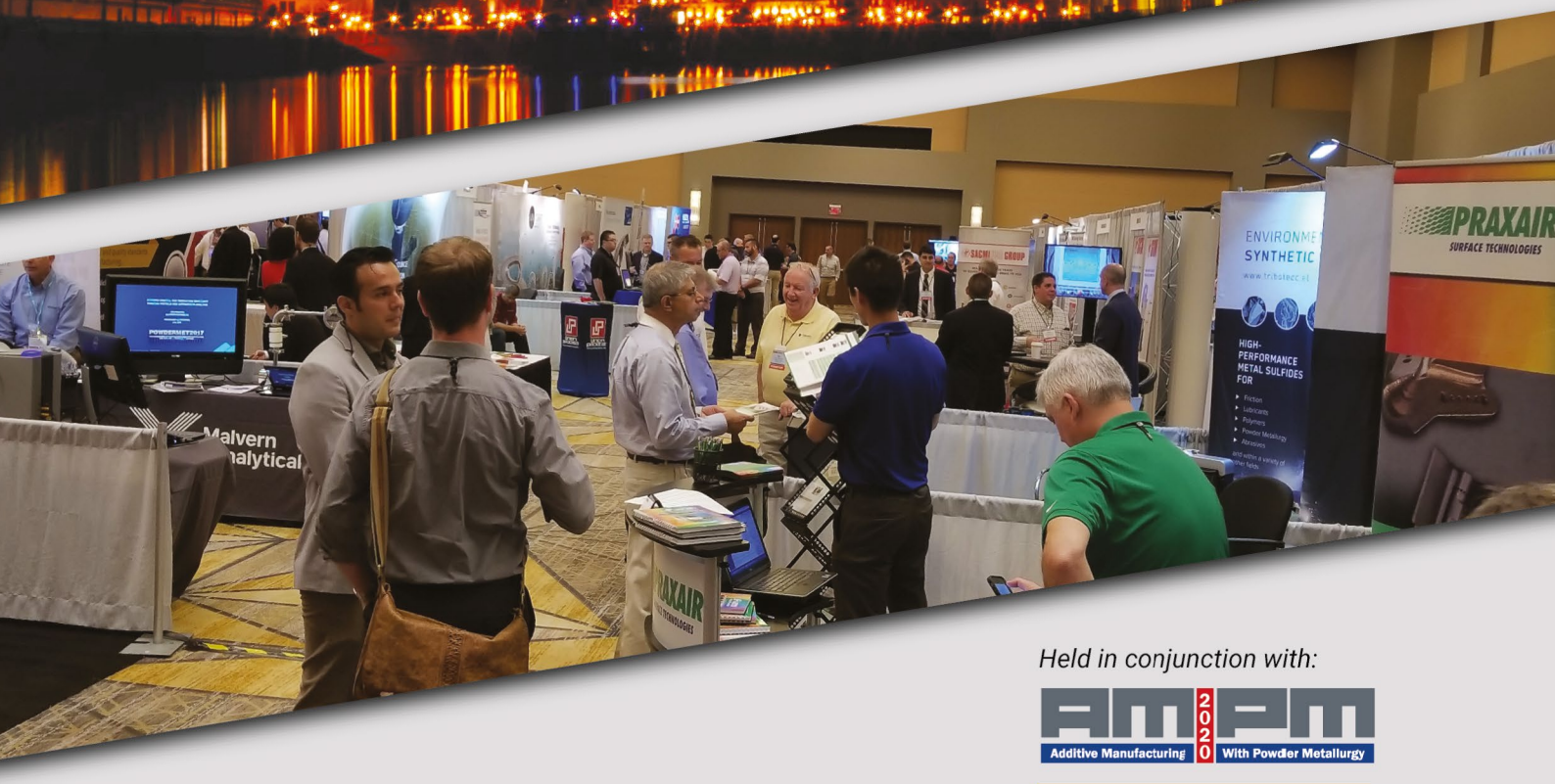
The institute presents a range of awards, medals and prizes for published work and for contributions to the industry. Recent winners of the prestigious Ivor Jenkins award include Dr Leo Prakash (2019), David Whittaker (2018), and John Dunkley (2016). The closing date for nominations for the 2020 awards is January 31, 2020.

www.iom3.org

WorldPM2020 / MonTreaL

World Congress on Powder Metallurgy & Particulate Materials

Montréal / June 27–July 1, 2020 / Visit WorldPM2020.org



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Metal Powder Industries Federation
APMI International

Teardown showcases applications for PM in hybrid electric vehicle market

Following on from a teardown project in 2017, where a team of engineers at Höganäs AB stripped back three new vehicles to their component parts, the company recently repeated the exercise with a hybrid SUV from Chinese automaker BYD. The four-wheel drive BYD Tang is built for China's domestic market, and provided the team at Höganäs with the opportunity to establish a better understanding of the use of Powder Metallurgy in hybrid vehicles, as well as highlighting potential future applications. Anders Flodin, Application Development Manager at Höganäs AB, reports on the project.

Sweden's Höganäs AB has a track record of tearing down, redesigning and prototyping automotive transmissions. Over the years, the Smart Fortwo, Mitsubishi EVO X rally car and the M32 SAAB 9-5 have all undergone the process, resulting in rebuilt transmissions in which a number of traditionally made gears have been replaced with Powder Metallurgy alternatives. More recently, full vehicle teardowns have also been undertaken by Höganäs, in the hope of understanding how Powder Metallurgy is used in different vehicles and in different markets, and to uncover additional opportunities for powder metal technology.

As previously reported, the models chosen for teardown have included the Ford F-150, VW Passat and Toyota Yaris, with the results demonstrating how the content of PM found in a vehicle differs by model type, region and manufacturer [1]. These teardowns also highlight where alternative technologies are challenging the use of PM, for example by identifying automotive parts that were once produced by PM, but for some reason are not anymore.

Following the success of these teardowns, and to gain an insight into China's automotive industry, Höganäs recently purchased a BYD Tang, a 4WD plug-in hybrid vehicle built in China for the Chinese market. As reported in this article, Höganäs engineers were challenged with the task of dismantling the vehicle to its component parts to identify the content of, and potential for, Powder Metallurgy components in a typical Chinese-made hybrid vehicle (Fig. 1).

Fig. 1 The Tang PHEV from Chinese auto manufacturer BYD was the subject of this teardown (Courtesy Höganäs)

Fig. 2 The process of tearing down the BYD Tang took four days (Courtesy Höganäs)

The amount of PM can vary by vehicle sector and world region

The results of Höganäs' previous teardowns, as well as statistics published by PM trade associations, show that the quantity and weight of PM parts found in automotive applications can vary greatly depending on geographical region (Fig. 3), manufacturer and vehicle category. Typically, the statistics show that the USA has the largest weight of PM parts per vehicle, at around 20 kg, followed by Europe (10 kg) and Japan (9 kg), with cars made in China having a particularly low content estimated at just under 4 kg per vehicle.

Of course, there are many factors that influence these figures. In the USA for example, the average vehicle is larger than those found in Europe and Japan, thanks to the popularity of pick-up trucks and large SUVs. In China, vehicles tend to be smaller, and historically the use of PM to manufacture vehicle components has been relatively low.

China is also the world's biggest market for electric vehicles, reported to be larger than Europe and the United States combined. According to McKinsey, the market expanded by 72% in 2018 over the previous year, with around 94% of sales being from domestic manufacturers. The adoption of electric and hybrid vehicles has been encouraged by China's government, with numerous subsidies and incentives over recent years to ensure the country is at the forefront of this technology.

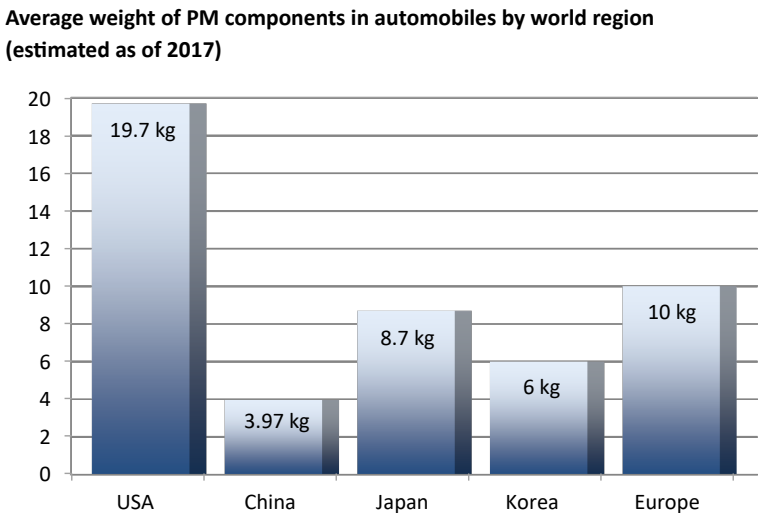

Fig. 3 The weight of PM found in automobiles in various regional markets [1]

Fig. 4 The ICE in a hybrid has components well-suited to PM. Although smaller in capacity, the parts may require the improved properties PM can offer (Courtesy Höganäs)

Although the percentage of electric and hybrid vehicles is relatively small, it is a sector that is still seeing growth, despite the current slowdown in automotive production. On the one hand, this market will offer many opportunities for Powder Metallurgy technology; on the other, the downsizing of ICEs in hybrid systems, and the development of pure electric vehicles, is also a threat to many of the more traditional PM applications.

Previous teardowns: Ford F-150, VW Passat and Toyota Yaris

As mentioned, Höganäs has already completed teardowns of the Ford F-150, Volkswagen Passat and Toyota Yaris. The Toyota Yaris, reported to be the second best selling car in Japan at the time of the project, was the team's first purchase. Although unavailable as a hybrid in Japan, this option is available in Europe and showcases Toyota's hybrid technology in a small family car. A 73 bhp 1.5 litre petrol engine and a 59 bhp electric motor combine via the car's CVT automatic gearbox.

The Passat GTE PHEV was, at the time, a new model from Volkswagen. It was reported to allow up to 50 km of driving at highway speeds in pure electric mode. The mid-sized family car is powered by the combination of a 154 bhp 1.4 TSI petrol engine and a 114 bhp electric motor, giving a total system output of 215 bhp.

With the US auto market dominated by sales of pick-up trucks and SUVs, the Ford F-150 was chosen for the third teardown. The particular F-150 model used had a ten-speed automatic transmission co-developed with GM and shared with a number of Ford and GM vehicles. This model is also known for a number of weight saving features, with aluminium body panels attached to a steel frame.

Results from these teardowns were varied, and highlighted the different approaches to the use of Powder Metallurgy among different automakers. It was found that the Ford F-150, for example, contained around 32 kg of Powder Metallurgy components, while the Toyota Yaris contained just 3.2 kg, a factor of ten less. When comparing the overall weight of the vehicles, with the F-150 being 2200 kg and the Yaris being 1160 kg, there is only a factor of two

"Results from these teardowns were varied, and highlighted the different approach to the use of Powder Metallurgy by the different automakers."

Fig. 5 The electric motors provide drive to both front and rear wheels. Once removed from the vehicle, each was dismantled and its component parts identified (Courtesy Höganäs)

less. One could conclude that Ford, a large part of US car production, is pro-Powder Metallurgy, perhaps more so than Japan's automakers; however, more data is needed to fully support such a claim.

The full report on this teardown was published in PM Review, Vol. 6 No. 2, and can be downloaded directly from www.pm-review.com.

The BYD Tang plug-in hybrid

The vehicle chosen for this teardown was the Tang plug-in hybrid from Chinese automaker BYD. The updated, second generation of this class-leading model is a mid-sized crossover SUV, having a length of 4870 mm, width of 1950 mm, and height of 1725 mm. As a comparison, this places the vehicle between Volvo's XC60 and XC90 SUV models in overall size. In terms of curb weight, the BYD Tang weighs 2390 kg compared to 2174 kg for the Volvo XC60 and 2343 kg for the Volvo XC90, when in hybrid specification.

Power is supplied to the Tang's four-wheel drive system via a two-litre turbo charged ICE (Fig. 4), producing 320 Nm of torque, and electric drive motors front and rear adding 250 Nm and 380 Nm of torque (Fig. 5). Worth noting is that the total torque of the Tang is 950 Nm, whereas an all-electric high-performance Porsche Taycan Turbo S comes in at 1050 Nm and the Taycan Turbo at 850 Nm.

Dismantling the BYD Tang hybrid to its component parts

The teardown took place in Shanghai, with Höganäs engineers and workshop technicians dismantling and documenting the vehicle's parts (Fig. 6). As can be seen in Fig. 7, the BYD Tang has a complex driveline, with two electric motors, belt/starter/generator (BSG) unit and one internal combustion engine. The Volvo XC90, for instance, has one rear axle electric motor and one transversely mounted front ICE, with no electric motor on the front axle.

"The whole teardown process took four days and a database, together with a Prezi file, was compiled containing data and pictures of the parts for later analysis and presentation."

Fig. 6 The BYD Tang's components were sorted and catalogued (Courtesy Höganäs)

The whole teardown process took four days and a database, together with a Prezi file, was compiled containing data and pictures of the parts for later analysis and presentation. The weights, dimensions, and materials of the mechanical parts of the car were all recorded. Non-relevant parts, such as bumpers and fenders, were not accounted for. However, electric motors, inductors, coated parts and brazed parts were recorded, since these are all relevant to the PM industry.

Reassembly

During previous teardowns performed by Höganäs, it was discovered that there can be difficulty reassembling hybrid vehicles to make them fully functional again. For example, even with direct involvement from VW, the Passat PHEV could not be reassembled to a working state. It was possible to get the slightly less complicated Toyota Yaris to work again, however,

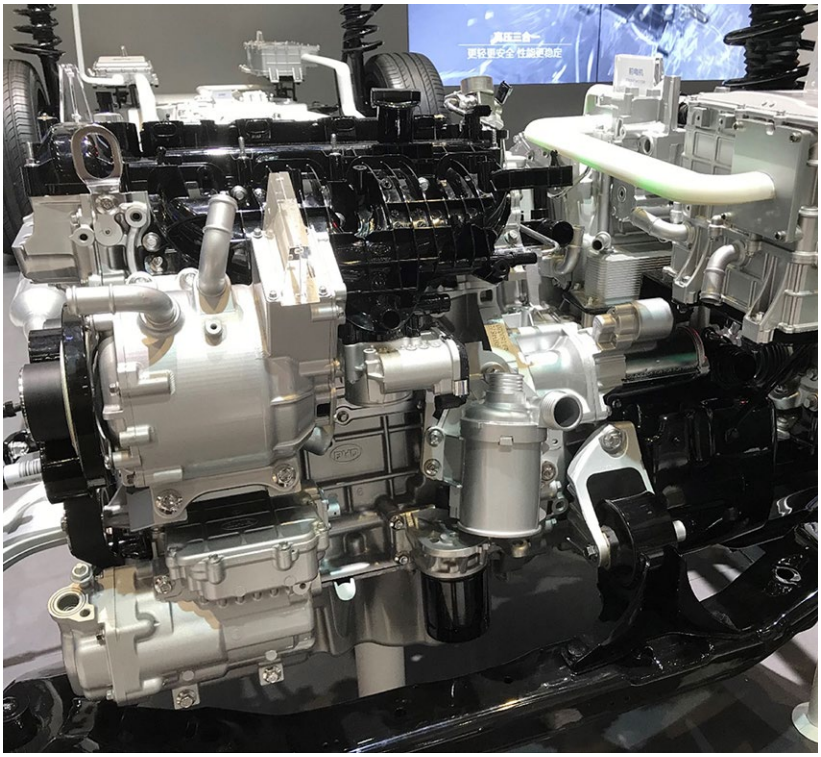

Fig. 7 The Tang's ICE, power electronics and DCT transmission, with the electric motor hidden behind the electronics. There is also a water-cooled belt/starter/generator unit in the forefront (Courtesy Höganäs)

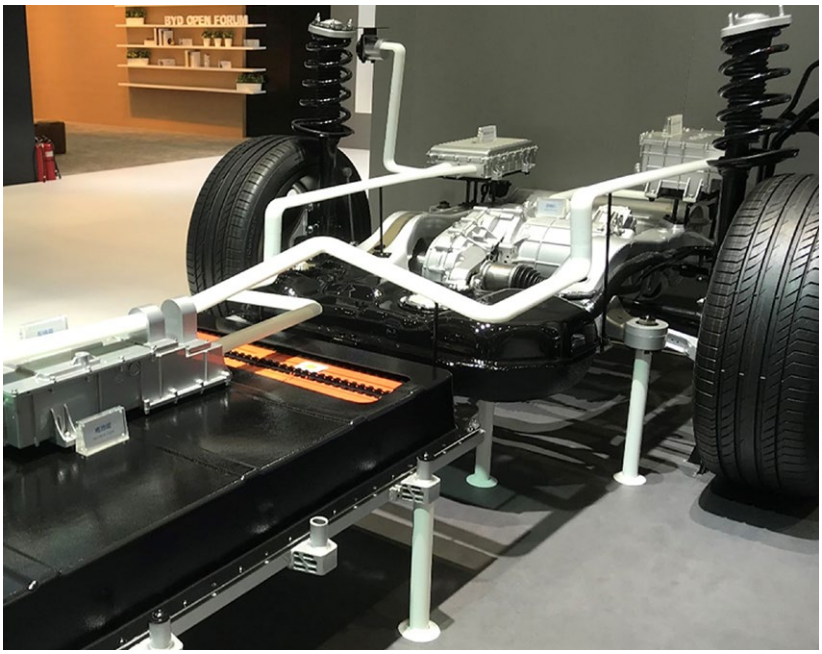

Fig. 8 Battery pack, electric motor and gearbox for the rear axle is visible (Courtesy Höganäs)

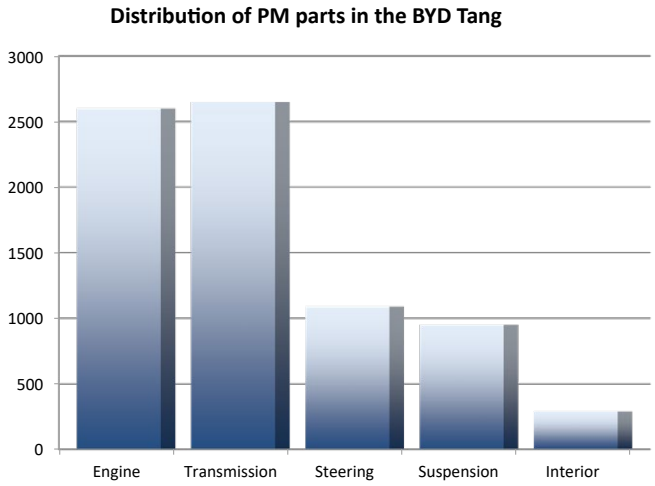

Fig. 9 Location of PM parts in the BYD Tang (Courtesy Höganäs)

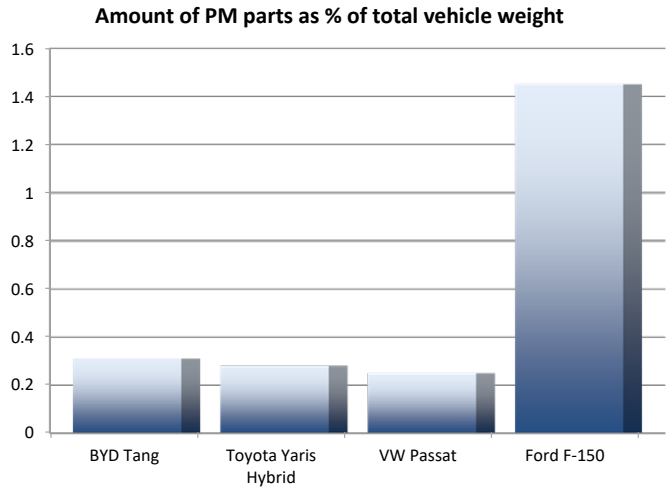

Fig. 10 PM penetration as a percentage of vehicle weight (Courtesy Höganäs)

the rebuild process proved difficult and required substantial help from Toyota master mechanics. Given the complex nature of the BYD Tang, it was therefore decided not to even attempt to rebuild on this occasion.

Fifty-four Powder Metallurgy components identified

In total, Höganäs found fifty-four Powder Metallurgy components in the BYD Tang. Once identified, the parts were grouped into the different subsystems as presented in Fig. 9, where it can be seen that just over 5 kg (around 65% of the total PM) is used in the Tang's engine and transmission. The electric power steering also contains a number of PM parts, as does the suspension system, each adding a further kilogram of weight.

In comparison to the earlier teardowns, the overall penetration of PM in the BYD Tang was found to be higher than in the Toyota and VW Passat, but considerably lower than in the Ford F-150. In relative terms, the percentage of PM, when compared to the vehicle weight, was around 0.3%, or 7.8 kg of the 2390 kg curb weight (Fig. 10).

The main PM applications included a VVT system, valve guides and synchroniser hubs, as well as a number of pumps containing PM parts. Also worth mentioning is the use of an Eaton differential with an automatic lock-up that contained a number of PM parts assembled into a very ingenious design (Fig. 11). The unit is a purely mechanical system, being self-energised and relying on centrifugal force and springs to engage once there is a 100 rpm wheel speed difference. It also has a mechanical safety switch that will prevent the differential locking up at high speeds, thereby preventing excessive impact loads on the parts. Most of the gears can be made by PM, either by powder forging or press & sintering, followed by case hardening (Fig. 12).

Around 120 missed opportunities for Powder Metallurgy

A further 120 components were identified as being suitable for PM, meaning that these parts are both possible to make via PM and could prove cost-effective. Although it is relatively easy to tell if a part can be made using Powder Metallurgy (with or without some design modifications), it is often harder to tell if a part will be cost effective or not. Cost effectiveness often depends on many factors, which differ between manufacturers and end-users.

During the different teardown processes, potential candidates for PM were identified and documented. Business case analyses for these parts have been established to single out the most interesting opportunities.

Fig. 11 The Eaton differential system contains a number of PM parts (Courtesy Eaton)

Transmission

The Tang's DCT transmission is a treasure chest of opportunities (Fig. 13). There are very few PM parts currently included there, but many of the steel parts offer the potential for conversion. The gears are prime candidates, along with the synchroniser sleeves (>1 kg). There are already 1.1 kg of PM synchroniser hubs in the transmission, but one hub is still not converted. The total gear mass, including synchroniser teeth, is close to 20 kg. Not all of the gears are good candidates for PM, however. For example, the big ring gear attached to the differential cage would require a very large press, and some of the gears are cut on the shafts, which makes conversion less straightforward.

At this stage the transmission has not been reverse-engineered for stress analysis, so the exact process route for each gear has not been defined. However, the potential for PM conversion is very real and, from a manufacturing point of view, approximately 12 kg of gears would make good candidates for production by Powder Metallurgy.

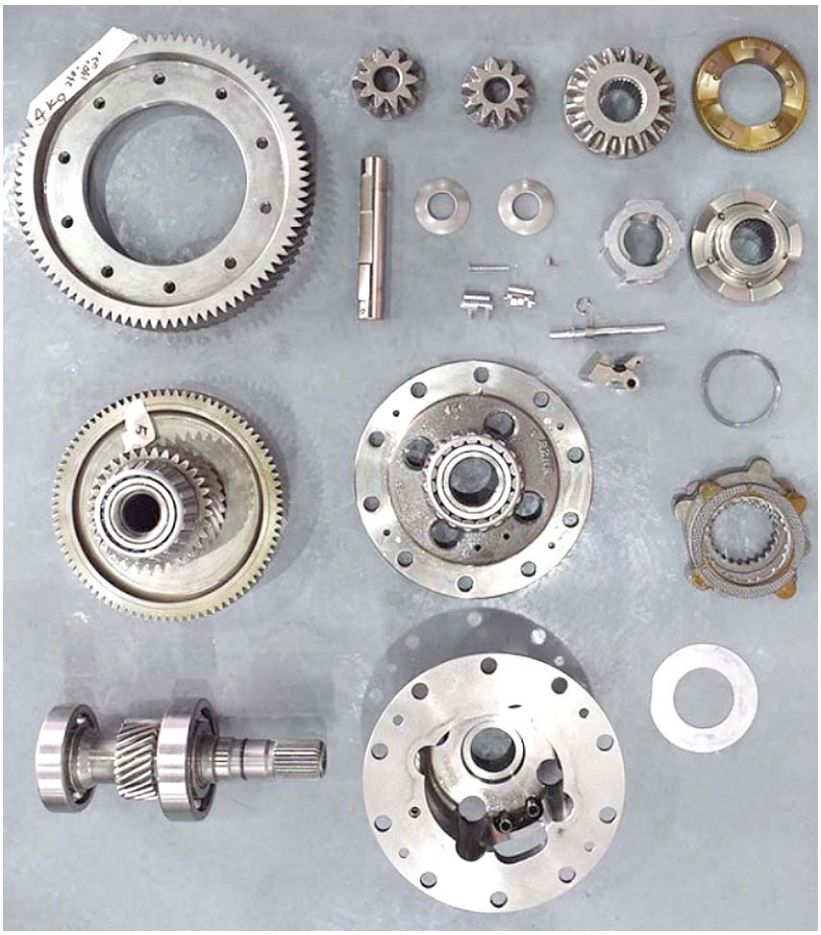

Fig. 12 The majority of parts found in the Eaton differential are either made via PM or could be ideal candidates for conversion (Courtesy Höganäs)

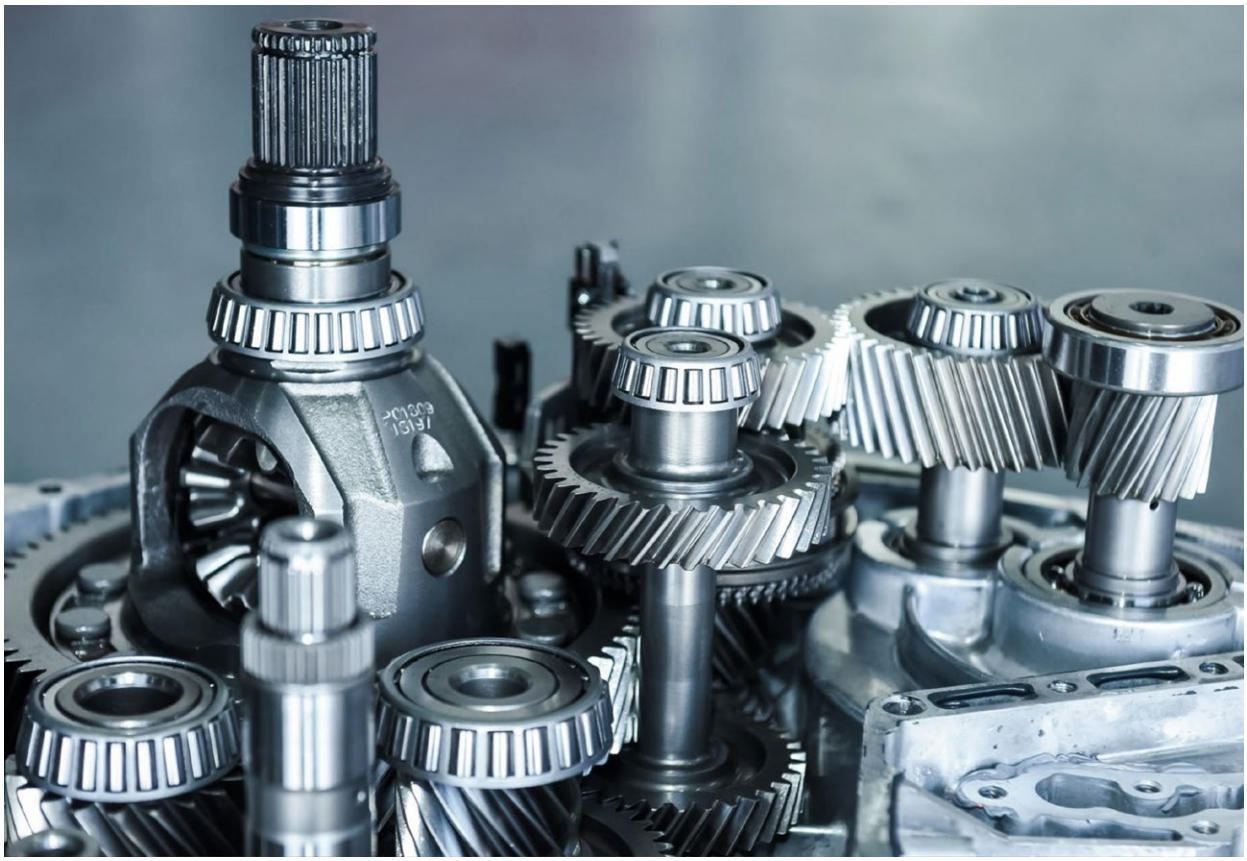

Fig. 13 The transmission houses many parts suitable for conversion to Powder Metallurgy (Courtesy Höganäs)

Engine/motor

In the combustion engine there are several good candidates for PM, such as the connecting rods (four at 691 g each) and three balancer shaft gears, weighing a total of 1.1 kg. In addition, the electric motors could have been made using soft magnetic composite powders. The exact amount needed to replace the steel is unknown, since the motors have not yet been redesigned, but a reasonable estimate is around 4-6 kg in each of them (Fig. 14).

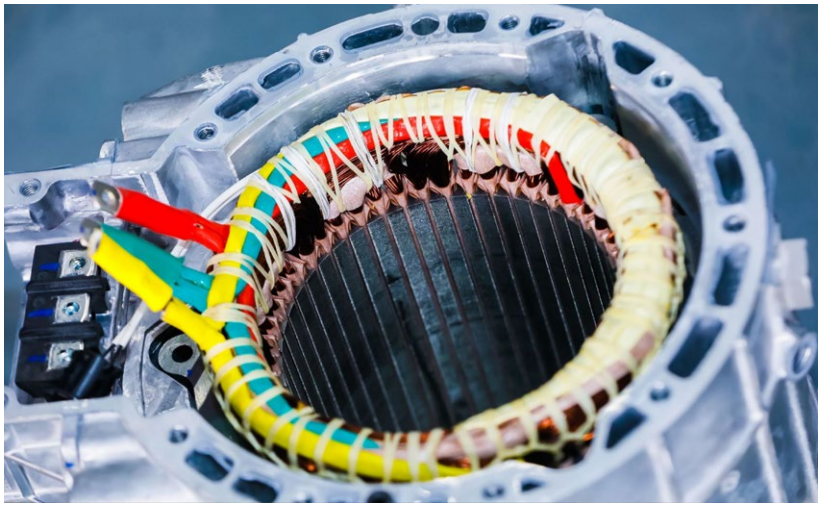

Fig. 14 Each electric drive motor has the potential to add a further 4-6 kg of PM if soft magnetic composite (SMC) iron powder is used in the stator core (Courtesy Höganäs)

Differential

In addition to the gears, there are other parts with the potential for convertion to PM. The bulk of these parts are made out of two differential cages, and one (not converted) synchronised hub mentioned above.

Differential cages may not currently be a common powder metal part, but could be constructed out of four PM parts using three different tools. The benefit would be lower weight, less machining, higher rigidity and most likely a lower cost. Höganäs has conducted an in-depth design study of this together with Alvier and KBE+, where the current design in the Toyota Yaris Hybrid was digitised and benchmarked against the PM design developed by Alvier, Höganäs and KBE+ (Fig. 15).

In this type of vehicle, with differentials on both front and rear axles, the total weight of differential cages is over 8 kg. The differential cage is also a component that will be in any vehicle, regardless of the type of driveline.

Other parts

Also identified in the teardown were parts that have traditionally been made from PM, but for some reason this was not the case in the Tang. An example of this was the car's seat adjuster gear, as well as the integrated crankshaft bearing shown in Fig. 16. Crankshaft bearings are an important PM part and contribute significantly to the total PM in a vehicle, with several hundred grams of PM being used in a four- or five-cylinder engine. As a reference, a bearing cap in the V6 of the Ford F-150 weighs 1.1 kg.

Summary

The teardown of the BYD Tang identified fifty-four parts currently being used in the Chinese-made hybrid model, totalling 7.8 kg. In comparison to the 2017 vehicle teardowns, content of PM in the Tang is slightly higher, relative to its weight, than those of the Toyota Yaris and VW Passat, but significantly lower than what was found in the Ford F-150.

The teardown highlighted a large number of components suitable for conversion to PM. The majority of these were found in the car's transmission, where many of the gears are good candidates for conversion. The engine could potentially hold another 3.5 kg in gears and connecting rods. The electric motors, if made with SMC technology, could also add a further 10 kg of PM.

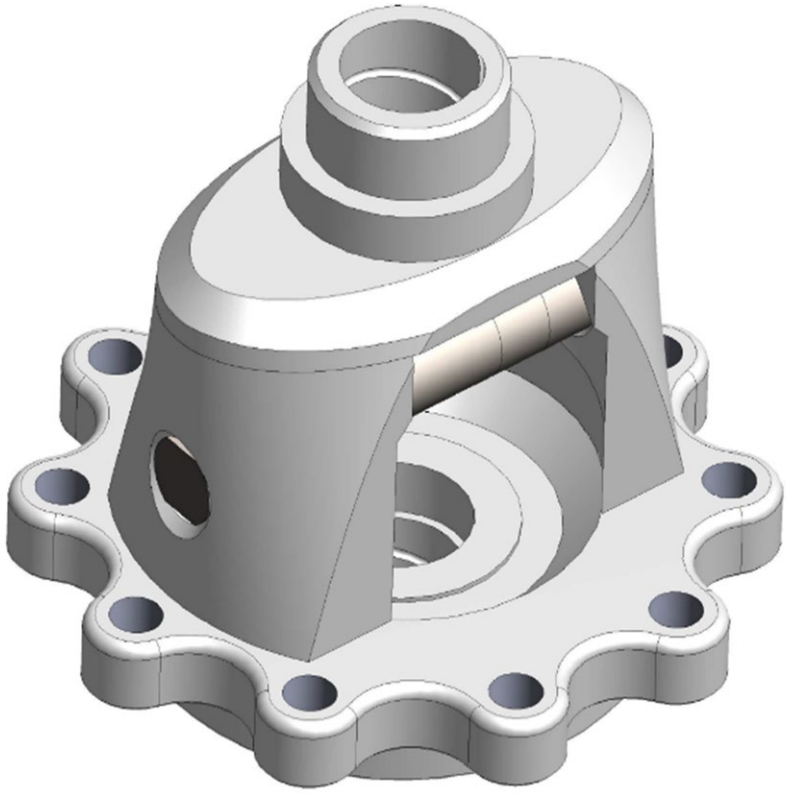

Fig. 15 First concept design of differential cage made from four PM parts. Shaft is still made of conventional steel (Courtesy Höganäs)

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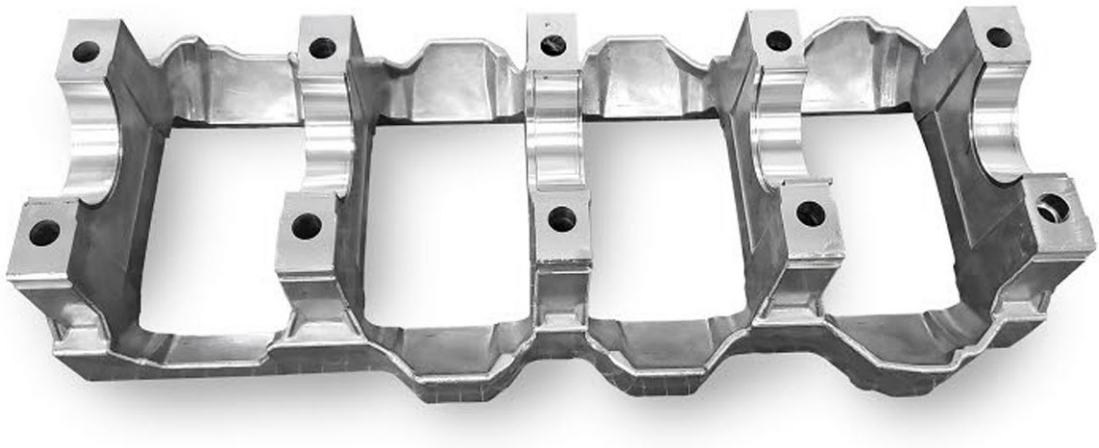


Fig. 16 Crank shaft bearing caps, such as these found on the Tang, have traditionally been made using PM, but were not in this case (Courtesy Höganäs)

Characterising powders for Cold Isostatic Pressing applications

An understanding of the characterisation of metal powders is essential for optimising production of high quality components during Cold Isostatic Pressing. In this article, Freeman Technology's Operations Director, Jamie Clayton and the company's Technology Manager – Materials Engineering, Jason Dawes, present an overview of the main powder characterisation processes used in industry and makes the case for the company's dynamic powder testing technology.

Over recent decades, the economic and technical advantages of producing metal components from powder have led to the steady displacement of conventional casting by near net shape (NNS) manufacturing techniques such as press and sinter Powder Metallurgy, Metal Injection Moulding (MIM), Additive Manufacturing (AM) and Isostatic Pressing. Such processes minimise the requirements for grinding and machining and can be used to produce complex components with unique properties. Material utilisation is typically high and energy input low, giving rise to overall production costs that can be as much as 60% lower than those associated with traditional manufacturing routes [1].

Exploitation of the full potential of NNS processes, however, relies on the ability to characterise metal powders to predict and optimise manufacturing performance. In this article, we consider which properties are influential in defining the performance of powders in NNS processes, focusing on Cold Isostatic Pressing (CIP), and highlight the powder testing techniques that can provide relevant information. An experimental evaluation of different iron alloy powders in a CIP process illustrates the value of dynamic powder testing.

The attraction of NNS manufacturing

Manufacturing techniques classified as NNS are valued for their ability to produce components with dimensions close to those of the required product, with minimal finishing. Such tech-

Fig. 1 Left to right: CIP Mould, as CIPed, as sintered, first machining pass, finished machined component (Courtesy Manufacturing Technology Centre)

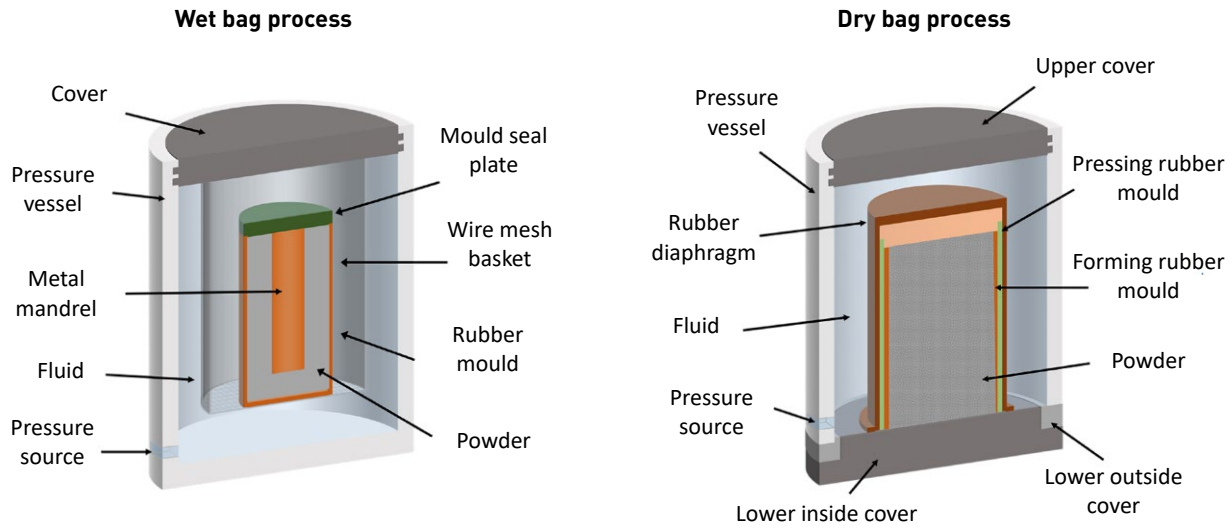


Fig. 2 CIP can be implemented as either a wet bag (left) or a dry bag process (right)

niques include closed die forging and investment casting, which use solid metal bars/rods and molten metal, respectively. However, here discussion is limited to Powder Metallurgy processes, notably CIP (Fig. 1).

Reduced waste is a primary attraction of NNS manufacturing, but minimal finishing requirements also translate to relatively simple processes with fewer steps than conventional alternatives. More generally, PM enables the use of materials such as high-melting point alloys that are unsuitable for conventional processing. The close control of key properties of the finished component, for example porosity, is an important capability, as is the flexibility to produce intricate and/or complex geometries. AM is particularly prized for its capabilities for rapid prototyping and inexpensive customisation.

The exploitation of these benefits relies on developing metal powder feedstocks that are well-matched to process requirements. While the optimal properties of a powder for any individual process are somewhat unique, certain characteristics, such as flowability, are universally important. The flowability of a metal powder defines its processability, and the efficiency of a NNS process, the speed and reliability of powder spreading in AM processes, for instance. Equally importantly, along with packing behaviour, a related characteristic, flowability directly impacts the properties of the finished component. Free-flowing powders that pack efficiently are often a prerequisite for a defect-free finished product.

Desired powder properties for CIP

In CIP, powder is loaded into a flexible elastomer mould shaped for the application, which is then subjected to elevated hydrostatic pressure. Fig. 2 shows the two variants of the process. In the wet bag process the mould is immersed directly in the pressurising fluid, a water/soluble oil mixture, while in the dry bag process the mould is permanently attached to the base of the high-pressure chamber and pressure is transmitted via a membrane. Complete filling of the mould to a uniform density is the first step of the process and relies on the powder flowing efficiently and consistently into all areas of the cavity. Flowability is clearly crucial, especially for more complex geometries.

Compaction pressures in the range of 200 to 750 MPa, depending on scale, are applied to produce a partially-dense compact with sufficient strength for transfer and sintering. Powder density typically increases from around 55–65% to 75–85% of its theoretical value with the hydrostatic pressure applying uniform compaction in all directions. This is an important advantage relative to techniques involving unidirectional pressing in rigid dies that produces uniform density in the finished component. However, any failure to achieve a complete fill or uniform density in the filled mould can cause inconsistent transmission of the compaction pressure producing an incomplete moulding and/or a poor surface finish. This analysis further emphasises the importance of flowability and packing behaviour, but it is also critical to recognise that compaction must produce a stable green body for transfer. Although the powder must be relatively free flowing at low stress, at elevated pressure inter-particular forces must be strong enough to form a continuous component.

Sintering of the green body, the next step, involves heating to significantly elevated temperatures below the melting point of the metal. It causes the metal particles to bond, increasing the strength of the component and further densifying the component. Re-pressing and other post sintering processes such

as surface cold rolling, infiltration and impregnation enable close control of the properties of the finished product and complete the process.

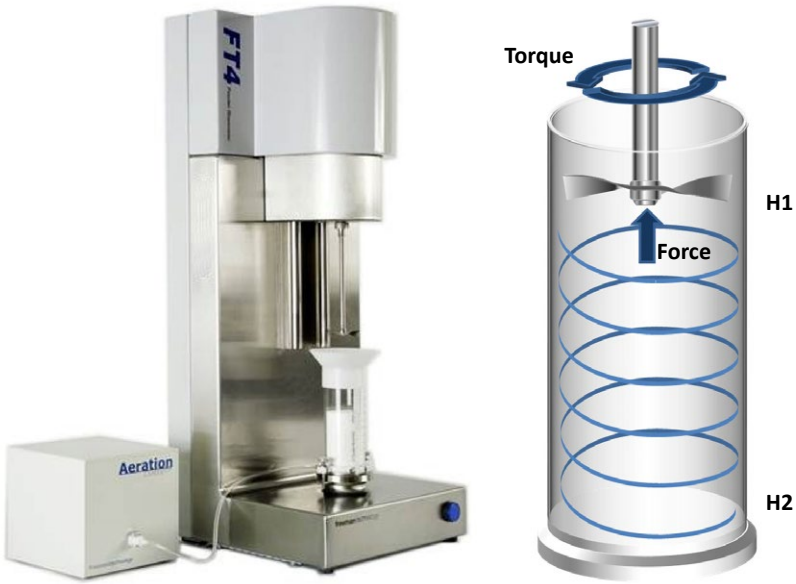
An important attraction of CIP is that it offers greater flexibility with respect to component geometry than rigid die processes. In addition, the lack of die wall friction minimises residual stresses in the green body, reducing the likelihood of cracks, strains and lamination in the finished product. These characteristics make CIP suitable for the manufacture of both simple and complex shapes including long thin-walled cylinders, parts with undercuts and/or three-dimensional curved geometries. Other practical benefits include the ability to press multiple shapes simultaneously and relatively low tooling costs. CIP was originally developed to produce tungsten and molybdenum billets; examples of commercial products routinely manufactured today include molybdenum and tungsten arc furnace melting electrodes, rollers and dies made from hard metals and refractory crucibles [2, 3].

However, CIP has certain limitations, a key disadvantage being relatively poor dimensional tolerances compared with metal die compaction. One reason for this is the flexibility of the mould, another is the potential for variability in the poured density of the powder within the mould. The second of these factors, however, can be minimised by the identification of metal powders with optimal properties for CIP.

Measuring powder flowability

The widespread industrial relevance of powder flowability is reflected in the range of techniques routinely used to measure it. Traditional, manual methods include angle of repose and flow through an orifice, as used to generate Hall Flow Index, a standard specification for metal powders [4]. A Hall's Flow test is simple, intuitive and quick to execute. A known mass of powder is charged into a funnel and then allowed to flow out through an orifice of defined diameter. Measuring the time taken for the funnel to empty provides an indication of flowability.

Certain limitations of the Hall Flow test highlight some key points about powder testing and are important to consider when it comes to selecting a testing method for CIP applications. For example, samples producing a 'null' result i.e. failing to flow through the orifice cannot be differentiated, even though they may perform differently. More crucially the Hall Flow test is a low-sensitivity technique and the resulting data typically exhibit poor repeatability. Though this can be partially attributed to the manual nature of the analysis, a more significant issue is the lack of any defined sample preparation. The sample is simply poured into the discharge funnel with no control over packing/density which can consequently exhibit variability. These limitations make this and other traditional techniques ill-suited to the precise differentiation required to successfully select powders for CIP applications.



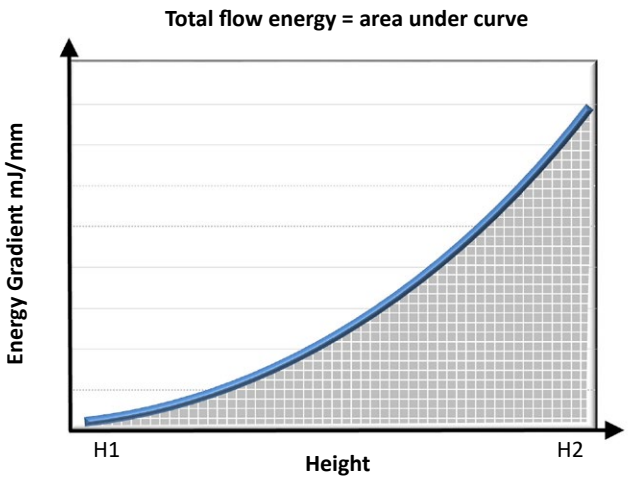


Fig. 3 Dynamic testing quantifies powder flowability under the low stress conditions of most relevance to mould filling and can also be used to directly investigate the response of the powder to air

Shear cell analysis is also a widely accepted powder testing method. It involves measurement of the force required to shear one consolidated powder plane relative to another and generates metrics including flow function coefficient (FFc) and unconfined yield strength (UYS). Shear cell testing involves greater control of the test environment and with a good instrument repeatability can be high. However, the technique is better suited to more cohesive samples, rather than the relatively free-flowing metal powders required for NNS processes, and primarily informs on incipient failure - the transition of the powder from the static to the dynamic state - rather than directly on flowability. Furthermore, testing is necessarily carried out under moderate to high stress, conditions that are far from representative of the low stress/vibrational process environment associated with CIP mould filling. Powder flowability is a complex function of many variables and inferring behaviour under conditions different from those applied during measurement is highly unreliable.

Dynamic powder testing was developed specifically to measure flowability under conditions that simulate the process environment and can be used to characterise powder behaviour across the entire stress range encountered in processes such as CIP. Dynamic powder properties are generated from measurements of the axial and rotational forces acting on a blade as it rotates through a sample along a precisely defined path (Fig. 3).

"Dynamic powder testing was developed specifically to measure flowability under conditions that simulate the process environment and can be used to characterise powder behaviour across the entire stress range..."

Samples can be measured in a consolidated, moderate stress, aerated or fluidised state to generate a range of parameters including:

- **Basic Flowability Energy (BFE)** which quantifies confined or forced flow behaviour in a low stress powder and is measured with a downward traverse of the blade that pushes the powder against the confining base of the test vessel.
- **Specific Energy (SE)** which quantifies unconfined or gravity flow behaviour in a low stress powder and is measured with an upward traverse of the blade that applies a lifting action.
- **Aeration Ratio (AR)** which is the ratio of BFE to Aerated Energy (AE), where AE is a BFE measurement made with air flowing up through the sample at a known velocity.

The well-defined methodologies associated with dynamic testing include sample conditioning, a defined cycle of gentle displacement of the powder bed that eliminates processing history and leaves the sample in a homogeneous, consistently packed state. These methodologies in combination with the precision engineering of dynamic instrumentation make the technique highly repeatable. Dynamic powder testing offers unrivalled sensitivity.

Dynamic powder testers, as exemplified by the FT4 Powder Rheometer, also enable shear and bulk powder property measurement - bulk density, compressibility and permeability. Permeability is determined from measurements of the pressure drop across a powder bed at a defined air flow rate and is particularly relevant for filling applications as the backflow of air, through the incoming powder, is essential for efficient filling. Compressibility quantifies how the bulk density of a sample changes as a function of applied consolidation pressure, so it too is highly relevant to the CIP process.

The following case study shows the application and value of multi-faceted powder characterisation for rationalising the relative performance of a range of metal powders in CIP and identifying which parameters are most valuable in defining powder performance for the application.

Case study: Characterising iron alloy powders for CIP

Six iron-based alloys were evaluated for suitability in a CIP process. Half of the samples were produced by gas atomisation – AGN, BGN and EGN – the other half by water atomisation - AWY, BWN and CWN. Samples of each alloy were vibration packed and sealed into polyurethane bags (moulds) of cylindrical geometry and then pressed at 370 MPa for 60 s. Final pressed dimensions were approximately 20 mm diameter by 110 mm length.

The success, or otherwise, of the CIP process was determined by visual assessment with any failure to form a stable, single continuous billet indicative of unacceptable performance (see Fig. 4). Three samples rated 'unacceptable' were subsequently subjected to annealing with the aim of improving their performance; BWN (Annealed), CWN (Annealed) and EGN (Annealed). Annealing is a heat treatment that typically softens the powder and/or reduces residual amounts of surface oxygen and nitrogen. Table 1 summarises the process performance of all the alloys tested.

Hardness testing was carried out for all the alloys, annealed and as received, to determine whether differences in hardness could provide a rationale for CIP performance. Hardness was measured by indentation testing (Qness 30+ automatic, Golling, Austria), using powder samples mounted in phenolic resin, ground and polished to a 1 µm finish. The results presented are the mean values of ten measurements (see Fig. 5).

Looking first at the original six alloys, the AWY powder which delivers acceptable CIP performance cannot be differentiated in terms of hardness from the others, especially the AGN and BGN powders, which fail. However, annealing softens both the BWN and CWN alloys, switching them from unacceptable to acceptable process performance, but increases the hardness of the EGN sample leaving its performance

Fig. 4 Powders that formed a single continuous billet (top) were rated as having acceptable CIP performance while those that did not were designated unacceptable (bottom)

Sample	Atomisation Process	Acceptable CIP Performance
AGN	Gas	No
AWY	Water	Yes
BGN	Gas	No
BWN	Water	No
BWN Annealed	**Water**	**Yes**
CWN	Water	No
CWN Annealed	**Water**	**Yes**
EGN	Gas	No
EGN Annealed	**Gas**	**No**

Table 1 Only one of the six original iron alloy powders delivered acceptable CIP performance; annealing improved the performance of two alloys but not a third

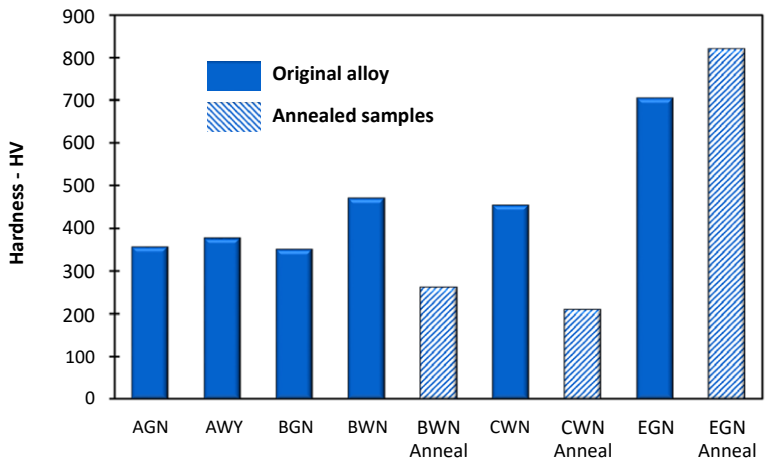


Fig. 5 Hardness data suggest that annealing has an important influence on CIP performance

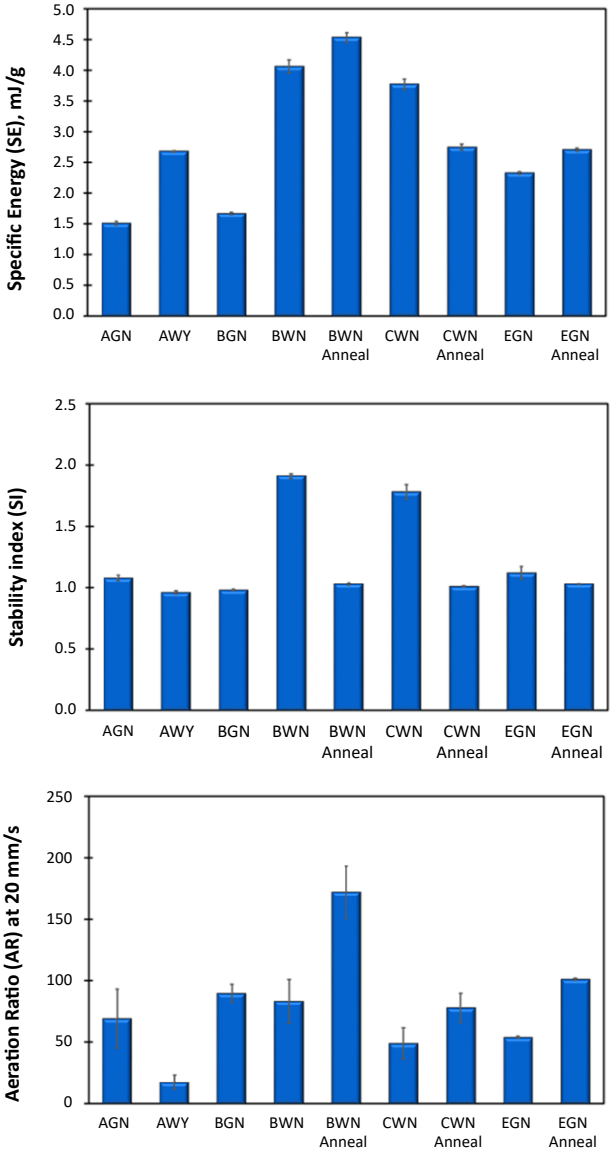


Fig. 6 Dynamic test data for the alloys shows that though the majority are stable (SI ~1) and relatively free-flowing (with a low SE and high AR) they can be robustly differentiated

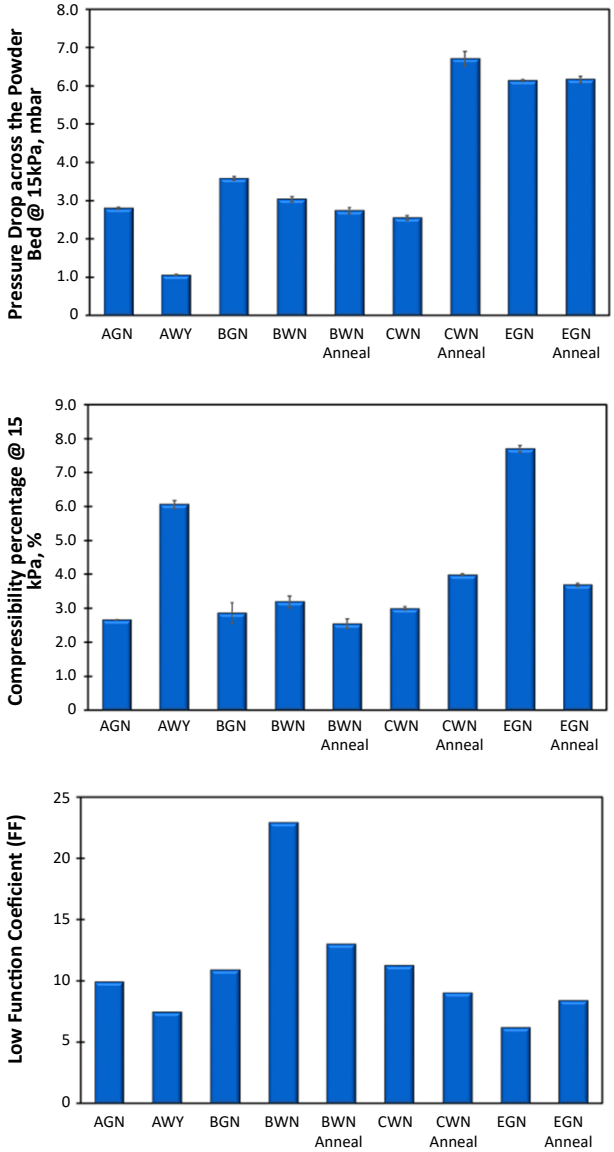


Fig. 7 Compressibility and permeability data indicate that in general the alloys exhibit relatively efficient packing (low compressibility/high permeability); shear testing classifies all nine alloys as either easy- or free-flowing

unchanged. Overall, these results suggest that hardness is significant in terms of CIP performance, but cannot, alone, rationalise all the observed differences.

To investigate possible correlations with other powder properties, particularly flowability, the samples were characterised in terms of dynamic, bulk and shear properties using the FT4 Powder Rheometer from Freeman Technology. All tests were run, in duplicate, using the 25 mm vessel for the instrument and standard test protocols [5]; a 25 ml sample was required for dynamic testing while shear and bulk tests were carried out with just 10 ml of sample.

Dynamic data clearly differentiate the samples though most have a stability index (SI) of around 1, a relatively low SE and quite high AR values (Fig. 6). SI is determined by measuring the BFE of the same sample multiple times (typically 7) and is the ratio of the value of flow energy measured in the last test to the original value. Values in the region of 1 indicate that most of the samples are stable, the exceptions being BWN and CWN which both have SI values of ~ 2. Lack of stability may be attributable to changes to the powder particles such as attrition or agglomeration or to other mechanisms such as the build-up of electrostatics.

Bulk and shear properties for the samples are shown in Fig. 7. Generally, compressibility values for the samples are relatively low, though there is clearly some variability; permeability values are quite high (low pressure drop), though

two of the annealed samples, CWN Annealed and EGN Annealed, and one of the original alloys, EGN, exhibit significantly lower permeability than the other materials. Overall these data are suggestive of efficient packing within the powders. The FFc values of the samples classify them all as either easy or free-flowing, 4<FFc<10 and FFc>10 respectively, indicating low cohesion values.

A multilinear regression (MLR) was performed, using Microsoft Excel Data Analysis Tools (Microsoft Office 2016), to elucidate the complex relationships between CIP performance and the measured properties and identify those of significance. Using the 'least squares' method, acceptable CIP performance was correlated with hardness and dynamic flow and bulk properties. Process performance was designated either as 1 (acceptable) or 0 (unacceptable). The acceptance criteria for the reliance factor (p) and the coefficient of determination (R^2) are ≤ 0.05 and ≥ 0.9 respectively. Using these criteria, a robust relationship was developed between CIP process performance and process properties:

Binary CIPability = 0.495 SE – 1.399 SI – 0.001 Hardness – 0.006 AR + 1.572 (R^2 = 0.9581)

This indicates that higher SE values and lower AR values are desirable from the perspective of CIP performance. SE values are primarily influenced by mechanical interlocking and frictional forces since the powder is moving in low stress state, under gravity. AR values, on the other hand, tend to be a function of the strength of inter-particular forces such as van der Waals, electrostatics and capillary bonding. In more cohesive powders, strong inter-particular forces inhibit the flow of air between individual particles, minimising its impact on the powder bed. Such powders therefore tend to be associated with low AR values. The derived relationship suggests that increased cohesion, high inter-particular friction and mechanical interlocking are all beneficial to the CIP process.

This is a somewhat counter-intuitive finding, given the importance of mould filling and the associated assumption that free-flowing powders will deliver optimal performance. However, during compaction it is cohesion, frictional forces and mechanical interlocking that promote the formation of a stable compact. Samples AGN and BGN, for example, have notably lower SE values than those that process acceptably, coupled with relatively high AR values. For these materials, filling the mould should be straightforward, but they are unlikely to compact to a single continuous component, despite their low hardness, due to the weakness of particle-particle interactions.

Conclusion

The effective exploitation and optimisation of NNS manufacturing technologies relies on being able to produce and select metal powders that are well-matched to process requirements. The reported study highlights the limitations of trying to predict CIP performance from just a single powder property and the strength of a multivariate approach using dynamic powder properties alongside hardness data. The importance of selecting a metal powder for CIP that will flow freely into the mould to ensure a complete and consistent fill is readily appreciated. However, since it is equally important that compaction of the powder produces a stable green body, a level of cohesion is essential.

Differentiating powders that will be successful from those that will fail requires a powder testing technique that can quantify both these critical aspects of behaviour with sufficient sensitivity. The results reported here illustrate the capabilities of dynamic testing within this context.

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JPMA Awards 2019: Showcasing innovations in PM for high volume applications

The winners of this year's Japan Powder Metallurgy Association Awards highlighted the continual developments being made by Japan's PM industry to further expand the use of PM technology. The winners included innovations in component design and powder production, demonstrating the continued potential for new applications in the automotive sector, as well as other high-volume application areas.

Development prizes

Grand prize:

4WD cam clutch mechanism

The Grand Prize award was made to Fine Sinter Co. Ltd. and Toyota Motor Corporation for their development of components used in the cam clutch disconnect mechanism for a four-wheel drive vehicle (Fig. 1). The mechanism is used to stop the rotation of the prop shaft when 4WD driving is not necessary, thus improving the fuel efficiency of 4WD vehicles with conventional engines.

Initially, production by forging and machining was considered. However, the two companies have been able to achieve significant cost reductions and exercise superior control over a number of product characteristics by adopting a Powder Metallurgy approach.

The cam clutch mechanism consists of four components identified as cam 1, cam 2, holder and piston, each with a complex shape. Cam 1 has an end-face ball groove and complex multiple steps. Cam 2 has a long thin wall, end-face ball groove and end-face ratchet shape. The holder has a wide end-face

Fig. 1 Disconnect parts produced by Fine Sinter Co. Ltd. and Toyota Motor Corporation. Left to right: Cam 1, Cam 2, Holder and Piston (Courtesy JPMA)

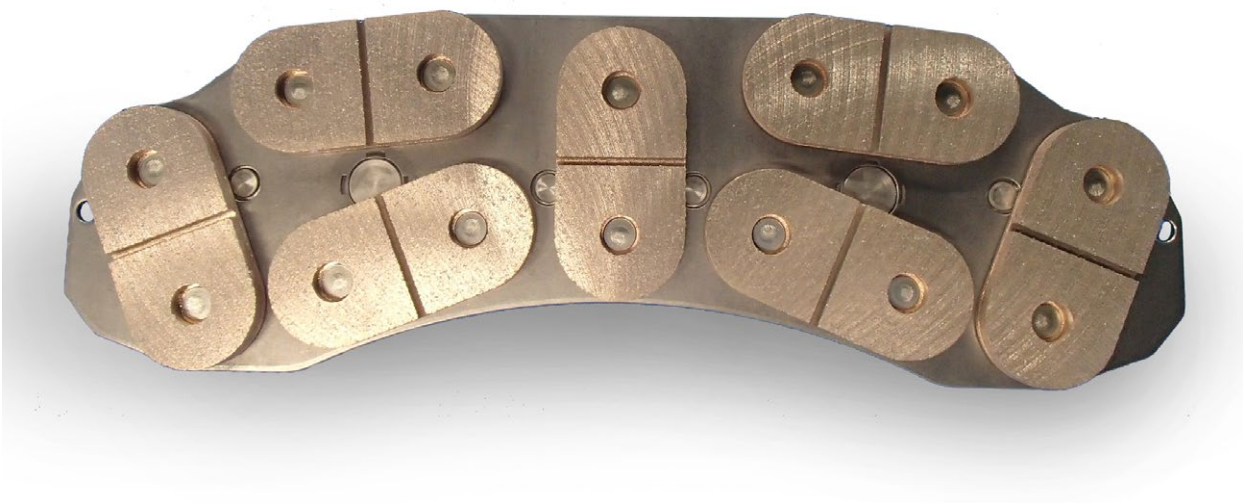

Fig. 2 Sintered brake lining for a new high-speed rail vehicle produced by Fine Sinter Co. Ltd. (Courtesy JPMA)

ratchet shape and the piston has an end-face ratchet shape (tapered side).

The PM components were designed to reduce the total number of parts required by the integration of features in the shape. Referred to as a Simultaneous Engineering product (SE product), the manufacturing involves the clever use of machining, rather than aiming at full net shape. This was achieved through the adoption of optimal machining processes and methods with minimum machining for near-net shape components. In relation to the mechanical properties of cam 1 and cam 2, which have ball grooves, it was necessary to increase the hardness of the surface layer of the ball grooves using laser quenching.

As a result, it has been possible to reduce costs by 65% per set, compared with forging and machining, with the product now installed in 4WD vehicles and contributing to improved fuel efficiency.

New design awards

Brake lining for new high-speed trains

The JPMA made six development awards in the New Design category. The first of these went to Fine Sinter Co. Ltd. for its Powder Metallurgy brake lining for a new high-speed rail vehicle (Fig. 2).

This product meets demands for stronger braking force, better wear resistance and lighter weight than conventional products, under both high speed and high load conditions.

Development of high-speed rail vehicles is progressing worldwide and test runs exceeding a speed of 400 km/h have been achieved. Commercial operations, at a maximum speed of more than 300 km/h, are already underway in Japan. The load applied to brake linings is becoming increasingly harsh, with the demands on brake systems becoming more stringent due to the miniaturisation of brake linings to achieve weight reduction.

A feature of this product is the unique mechanism for equalising contact pressure, which has been developed with the cooperation of end users and others. The contact pressure of this mechanism is more uniform than that of conventional products and it has become possible to lower the maximum temperature of the lining and the disk.

This development has delivered a reduction in the strong braking force from high speeds and the amount of brake wear. Also, by reducing the friction material sliding area compared with conventional products, the amount of friction material used has been reduced by about 30% and the weight of the brake lining has been reduced by about 20%.

As a result, in addition to weight and cost reduction, the lining's application in high-speed rail vehicles has been made possible by increasing the braking force (applicable to braking from high speeds of more than 300 km/h), thereby contributing to performance improvement in high-speed railways.

"As a result, it has been possible to reduce costs by 65% per set, compared with forging and machining, with the product now installed in 4WD vehicles..."

Fig. 3 Double toothed sprockets for VVT mechanisms developed by Sumitomo Electric Industries Ltd. through a process route using green machining (Courtesy JPMA)

Double toothed sprockets with the application of green machining

The second new design award went to Sumitomo Electric Industries Ltd. for the manufacture of double toothed sprockets for variable valve timing (VVT) mechanisms (Fig. 3), through a process route involving green machining.

The advantages of machining in the green state are extremely high productivity, due to the life extension of cutting tools; increased cutting speeds due to the lower cutting resistance; and the suppression of burrs generated from machining. However, a critical issue Sumitomo Electric Industries had to counteract is that green compacts can be prone to chipping during machining due to their low strength.

Accordingly, measures were taken to alleviate this problem by optimising the machining method and conditions. A specially-designed side cutter was adopted to machine the green compact appropriately while preventing it from being chipped due to stress concentration, and a jig was attached to prevent gear chipping. These measures did not interfere with productivity in line production.

As a result, a cost reduction of 5% was achieved for the sprockets, contributing to an overall cost reduction for the VVT system. In addition, chips generated by green machining are expected to be recycled as raw material powder, leading to a reduction in scrap.

Variable displacement oil pump components

Next, a new design award went to Diamet Corporation for vane rotors and cam ring parts used in variable displacement oil pumps in automotive engines (Fig. 4).

Fig. 4 Cam ring part and vane rotor for variable displacement oil pumps in automotive engines, produced by Diamet Corporation (Courtesy JPMA)

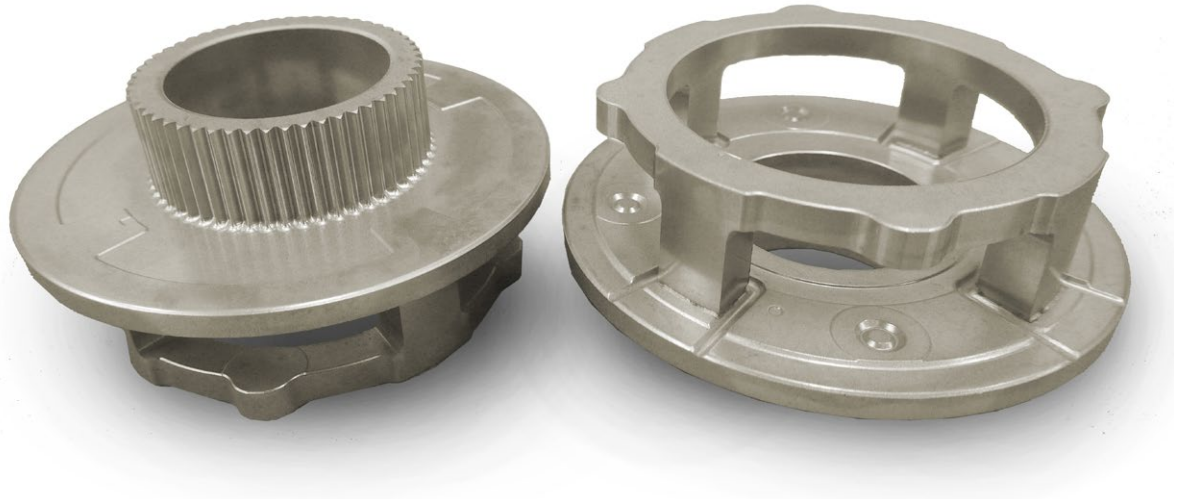

Fig. 5 Lightweight sintered planetary carriers for Dual Clutch Transmissions produced by Sumitomo Electric Industries Ltd. (Courtesy JPMA)

This type of oil pump can improve engine fuel efficiency and has recently been used in a number of vehicles. Vane rotors and cam ring parts are used for higher pressure pumps than usual, so high strength and dimensional precision are necessary for the grooves of the vane rotor and high resistance and dimensional precision are necessary for the inside diameter of the cam ring.

To obtain a high-strength vane rotor, increased density was needed, but there were problems regarding buckling of the thin regions of the die. As a countermeasure against buckling, the raw material was improved to reduce compressive stress during forming and the shape of the die was optimised to reduce stress concentration using FEM analysis. As a result, the overall density achieved was 7.15 g/cm^3 in normal compaction without die heating and a sufficient strength was achieved.

The high dimensional precision of the groove width was achieved without machining by optimising partial density balance, sintering positioning and sizing pressure. The dimensional scatter was within 0.025 mm (overall length 30 mm).

An internal roundness of 0.005 mm or less in the cam ring was achieved by optimising the chuck pressure during machining, and internal wear resistance was improved by adding steam treatment.

As a result, these parts were adopted in the variable displacement oil pump, which is expected to increase in demand, and contributed to improving the overall fuel efficiency of the engine.

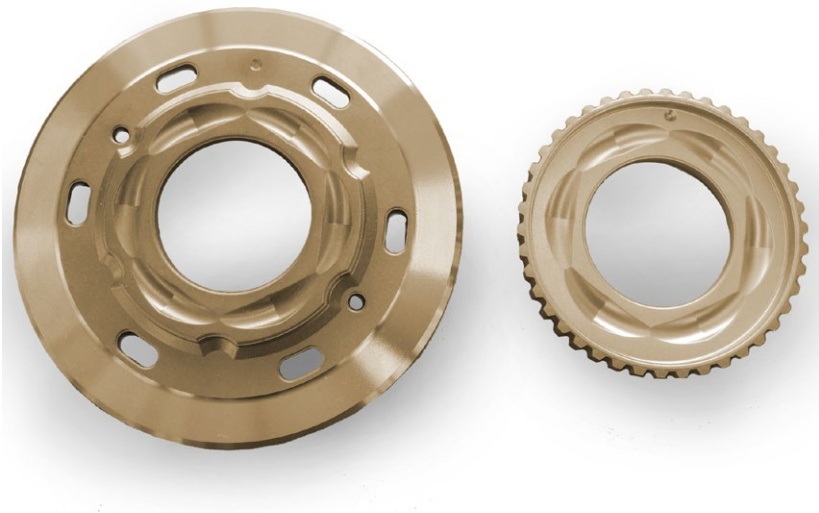

Fig. 6 Sinter-hardened 4WD cam parts produced by Sumitomo Electric Industries Ltd. (Courtesy JPMA)

Lightweight iron-based sintered carriers that can replace aluminium products

Sumitomo Electric Industries Ltd. received a second new design prize for its lightweight sintered planetary carriers (Fig. 5) for Dual Clutch Transmissions (DCT), developed to replace aluminium parts.

Design modifications to the component shape allowed the satisfaction of three customer requirements, related to the increased mass associated with replacing aluminium with the sintered material. Firstly, Sumitomo Electric Industries achieved a weight reduction with an appropriate redesign to satisfy the torsional torque requirement, which was achieved through an investigation of the relationship between the cross section of the pillar and

the torsion torque level using CAE, resulting in approximately 65% reduction in the pillar cross-sectional area. Secondly, the company reduced machining man-hours through the design of the blank shape while concentrating on precision processing of the boss circumference spline tooth tip. Thirdly, it achieved a compact design by improving the shape of the brazing junction for controlling the overflow of brazing material. Furthermore, the degree of assurance of 100% brazed joint inspection was improved by introducing an ultrasonic flaw detector.

As a result, the weight reduction achieved for products with this design was superior to that of parts produced using the conventional sintering method, leading to the adoption of the lightweight iron-based sintered carriers in the DCT mechanism.

Fig. 7 Oil-impregnated bearings used in the reducer of an electric parking brake, produced by Diamet Corporation (Courtesy JPMA)

Sinter-hardened 4WD cam parts with high bending fatigue strength

Sumitomo Electric Industries received a further award for the development of sinter-hardened 4WD cam parts with high bend fatigue strength (Fig. 6). The parts are the 'cam main' and 'cam pilot' used in electronically controlled 4WD coupling systems that switch between 2WD and 4WD in front engine, front drive (FF) vehicles.

PM has traditionally been adopted as a manufacturing method for these products due to its ability to form the cam groove net shape. However, competition from an alternative production method has led to the demand for further cost reduction in the sintered parts. To meet this requirement, a carburising, quenching and tempering process, originally introduced to improve the surface fatigue and bending fatigue strength of the cam groove, has been converted to a sinter-hardening manufacturing method that performs sintering and quenching simultaneously.

The adopted material was Fe-Ni-Cr-Mo-C, including Cr for high hardenability and Ni for the improvement of toughness. Bending fatigue strength was increased by 8% compared to the previously-used material and by 18% compared to a Ni-less material, when optimising the blending amount. The die design and spline density of the 'cam main' were improved to ensure a bending fatigue strength equivalent to that of the conventional product material, due to the fact that the stress was concentrated at the spline teeth roots, in addition to material optimisation.

As a result, the elimination of a sizing and quenching stage resulted in the achievement of a cost reduction of around 10%, thus preventing the customer switching to the alternative manufacturing method.

Sintered oil-impregnated bearings for electric parking brake

Diamet Corporation received a further new design prize for its sintered oil-impregnated bearings (Fig. 7) used in the reducer of an electric parking brake (EPB).

EPBs generate braking force using a small motor installed in the car wheel. The component requires high durability to ensure long-term reliability of the braking operation. It was also necessary to reduce production costs in order to further expand the adoption of these products.

To meet the required specifications the bearings had to demonstrate excellent seizure resistance under instantaneous high load operation. This was satisfied by using a material with excellent lubricity, consisting of bronze with graphite reinforced by the addition of phosphorus.

The design had to incorporate O-ring shape protection, meaning that for the chamfer of the flange on the outer diameter, a square shape would not be acceptable. Any reaction between the O-ring and lubrication was prevented by adopting glycol-based lubricating oil.

Fig. 8 Premixed iron powder produced by JFE Steel Corporation (Courtesy JPMA)

New powders

Premixed iron powder with machinability improvement in wide range of cutting conditions

A new powder development prize was awarded to JFE Steel Corporation for a premixed iron powder with machinability improvements over a wide range of cutting conditions (Fig. 8). Conventional raw materials with machinability improvements have delivered excellent machinability in a limited cutting speed range, for example, the low-speed range (100 m/min or less) or middle/high-speed range (higher than 100 m/min). In recent years, various cutting methods have been performed on a single component because of the growing demand for sintered parts with high dimensional accuracy and complex geometry. The cutting methods include processes such as lathe turning and drilling at various cutting speeds. Therefore, a raw material with excellent machinability over a wide range of cutting conditions was required. This newly-developed raw material contains multiple machinability additives, corresponding to the low cutting speed range and high cutting speed range.

In the low cutting speed range, it was thought that fine chips were effective in shortening the contact time between the tool and the chips. An additive with cleavability was selected. This additive can generate cracks in the chips and make the chips finer. In the middle or high cutting speed range, a protective and lubricating layer on the tool surface was thought to be effective in preventing thermal degradation. An additive to control melting point was selected. This additive can melt and soften during cutting and form a protective and lubricating layer on the tool surface.

"The developed raw material was therefore effective in reducing tool wear in a wide range of cutting conditions...."

The raw material was developed using these additives. Turning performance was evaluated by comparing the machinability of sintered parts with the new raw material and conventional premixed iron powder without machinability additives. When this raw material was used, lower tool wear was confirmed both in the low cutting speed (100 m/min) and high cutting speed (200 m/min) regimes.

The developed raw material was therefore effective in reducing tool wear in a wide range of cutting conditions. Reduction of machining cost and improvement of productivity are possible by extending tool life. Many Powder Metallurgy manufacturers have confirmed that the tool life has been extended by 2~5 times by using this raw material.

Effort prize

Development of niobium-added stainless steel sintered material

Finally, two Effort Prizes were made. Firstly, Sumitomo Electric Industries received a prize for the development of a niobium-containing stainless steel material (Fig. 9).

This study was conducted to investigate how to prevent sensitisation, a characteristic of stainless steel sintered material used for the fixing of pressure sensors that measure the pressure of the gasoline particulate filter (GPF).

Sensitisation is a disadvantageous phenomenon that occurs during welding stainless steels, resulting from the combination of chromium, an element, that is important for corrosion resistance, and carbon contained within the material, which leads to the occurrence of defective products with poor weldability and loss of corrosion resistance.

Additives such as niobium and titanium are used to prevent the sensitisation of stainless steels because their affinity for carbon is higher than that of chromium. The addition of niobium was therefore examined in term of cost reduction.

Stainless steel material in sintered parts for desensitisation was developed in cooperation with both automobile and parts manufacturers, since the addition of niobium to stainless steel material for sintered parts was unprecedented. The investigation of the addition of niobium to sintered stainless steel material was executed to clarify the following issues: the degree of effectiveness of its desensitisation effect, the influence on various mechanical characteristics, the impact on productivity and the optimum manufacturing conditions for satisfactory products.

Results of experiments with Fe-17Cr stainless steel indicated that the addition of 0.3 mass% of Nb or more prevents sensitisation and maintains mechanical properties at levels equivalent to those of conventional materials. Additionally, each optimum manufacturing condition was established using a process window index, which enabled mass production.

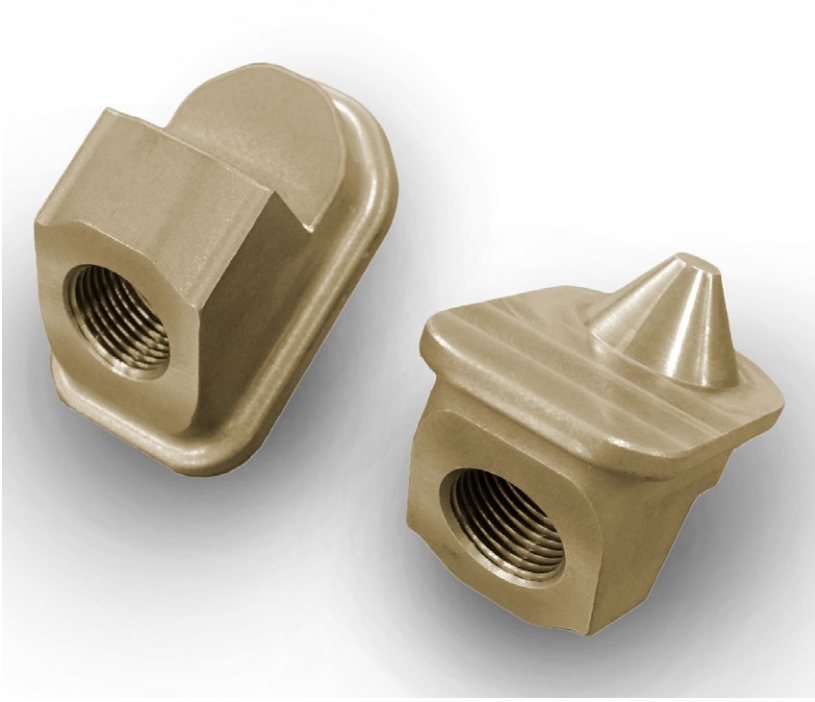

Fig. 9 Parts produced using a niobium-containing stainless steel material developed by Sumitomo Electric Industries (Courtesy JPMA)

Metal Injection Moulding of industrial robot components

A final prize was awarded to Fine Sinter Co. Ltd. for the development of a MIM component used in an industrial collaborative robot (Fig. 10). The part requires high accuracy, to less than 0.1% of the nominal dimension, high strength and high corrosion resistance, which had originally led to machined stainless steel being used. The conversion to MIM had the potential to save material and reduce cost.

To manufacture the parts to such a high tolerance, the process route would require a final machining stage. However, the design freedom of the MIM process allowed unnecessary part thicknesses to be reduced and strengthened with the addition of ribs. This reduced the overall amount of machining, compared with a fully machined part, by 80-90%.

Fig. 10 The design freedom of MIM allowed unnecessary part thicknesses to be removed and costly machining reduced (Courtesy JPMA)

The market for industrial collaborative robots is expected to grow, due to the increased needs for automation. With total cost savings of around 70-80%, MIM has now been adopted for the production of these components.

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Euro PM2019: Manipulating the sintered microstructures of hard materials

A technical session at the Euro PM2019 Congress, organised by the European Powder Metallurgy Association (EPMA) and held in Maastricht, the Netherlands, October 13-16, 2019, examined a variety of means to manipulate the sintered microstructures of hard materials (cemented carbides and cermets). The session featured one of the congress's five selected keynote papers, supported by three further papers on the subject. In this report, Dr David Whittaker provides an overview of the four presentations and highlights the work undertaken.

The dimensions of cemented carbide microstructures

Cemented carbides and cermets are one of the most widespread Powder Metallurgy products in the world. Found in broad application areas, such as cutting tools, wear parts, etc., they offer an outstanding combination of hardness and toughness. In the keynote paper presented by José García of Sandvik Coromant AB, Sweden, and co-authored by Verónica Collado Ciprés, Bartek Kaplan and Andreas Blomqvist, also of Sandvik Coromant AB [1], the authors summarised the broad dimensions of cemented carbide and cermet microstructures as an extension of a previously published review [2].

A wide range of microstructures, with specific mechanical properties, can be produced by selecting the appropriate combination of hard phases, metallic binder phase and processing parameters. This paper categorised the unique microstructure features as 1) WC morphology and chemistry, 2) Cubic-carbide-containing cemented carbide and cermets, 3) Functionally-graded cemented carbides and 4) Binder design of cemented carbides. The main features of each type of microstructure were discussed.

WC morphology and chemistry

A typical cemented carbide microstructure comprises tungsten carbide particles embedded in a cobalt (Co) metallic binder phase with no other phases present. The properties are dominated by the WC particle size and the binder chemistry and content.

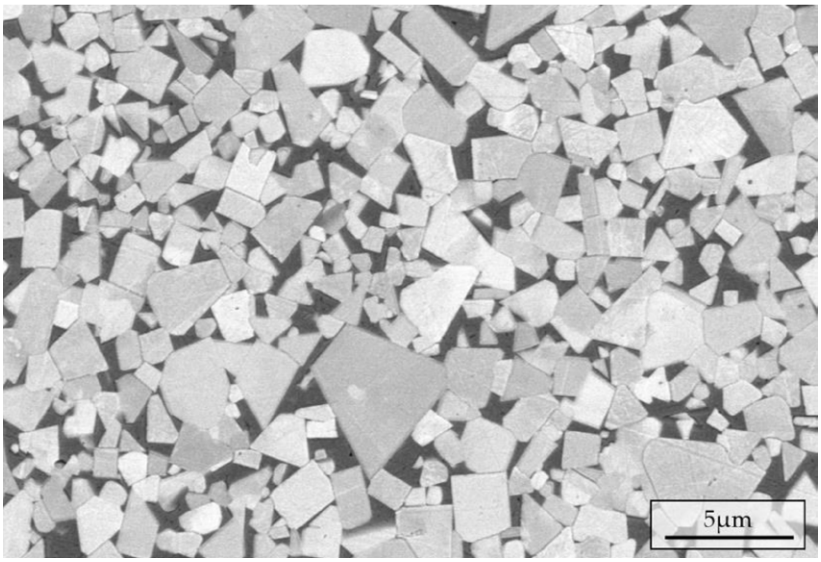

Fig. 1 SEM image of a WC-Co cemented carbide [1]

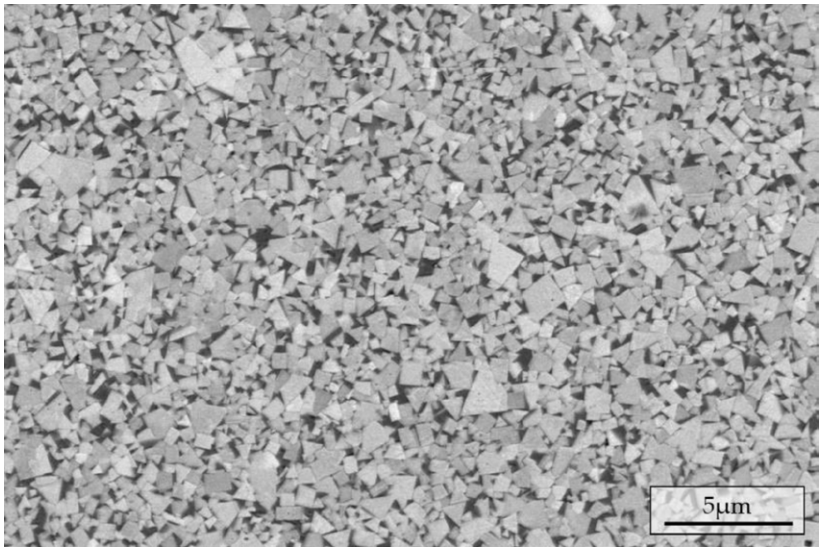

Fig. 2 SEM image of a fine-grained WC-Co-Cr carbide [1]

The WC grains form a skeleton with a defined contiguity. The size, composition, distribution and morphology of the WC can be tailored to achieve the desired properties.

Fig. 1 shows a Scanning Electron Microscopy (SEM) image of a WC-Co cemented carbide. The facetted WC grains (grey phase), forming a skeleton, are clearly recognised, as well as the matrix Co binder phase (dark phase). WC grains typically have a truncated trigonal prism morphology. In these microstructures, the WC particle size is usually above 0.9 µm. In certain applications, coarse (2.5-5.0 µm) or extra-coarse (> 5.0 µm) WC can be used. Hardness/toughness can be adjusted through the binder and WC phase ratio. Generally, coarser WC grains and larger volume fractions of Co binder will lead to tougher cemented carbides.

To increase the hardness of WC-Co cemented carbides, fine-grained microstructures have been developed. The WC particle size in the sintered microstructure does not usually exceed 0.6 µm. Such microstructures are produced by adding a small fraction of grain growth inhibitors that restrain the WC grains from coarsening during the sintering process. Established grain growth inhibitors in the hard metal industry are Cr, V and Ti. Addition of these elements is done in such a way that no cubic carbide phases are formed. An SEM image of a WC-Co-Cr cemented carbide is shown in Fig. 2.

Bi-modal WC hard metals have microstructures comprising two clear WC grain size fractions and tailored hardness/toughness properties can be obtained. Such microstructures can be intentionally achieved by mixing two different WC raw materials and controlling the grain growth during processing, or unintentionally as a result of abnormal grain growth.

The hexagonal WC phase is characterised by intrinsic properties, such as high hardness, high thermal and electrical conductivity and the ability to sustain plastic deformation by slip plane activation. Recent research has focused on modifying the physical properties of the WC phase by doping with other carbide formers, such as Cr, Ta or V. The nano-hardness of the WC phase can be tailored by the doping type. Both coarse and fine-grained WC-Co microstructures can be produced. Furthermore, the use of doped hexagonal-WC influences the formation of diffusion-controlled gradients in hard metals.

The shape of WC crystals can also be modified by doping additions. For example, doping with Ti prevents the nucleation of new basal planes during sintering, resulting in platelet-WC grains (Fig. 3). Platelet WC grains have few basal planes and high aspect ratios, both contributing to improved fracture toughness of the composites. Platelet WC crystallites increase the tortuosity of intergranular crack propagation in sintered cemented carbides.

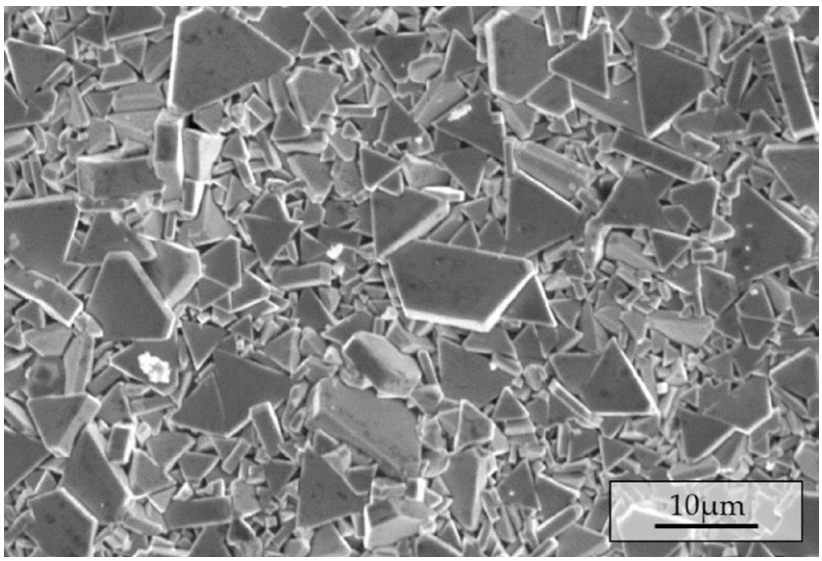

Fig. 3 SEM top surface image of a platelet-WC cemented carbide [1]

Cubic-carbide-containing cemented carbides and cermets

Carbides, nitrides and carbonitrides of Ti, Ta, Nb, Zr, Hf and V exhibit exceptionally high hardness and high melting point. They form solid solutions with WC of the type (Me,W)C with wide ranges of homogeneity and properties.

The addition of cubic carbides of the type TaC, NbC, TiC, etc., to WC-Co is state-of-the-art in improving wear resistance, hot hardness and plastic deformation. Adding cubic carbides to WC-Co mixtures leads to the formation of a secondary mixed carbide (Me,W)C in the microstructure, known as γ-phase. The γ-phase is recognised as a carbide with rounded morphology (Fig. 4) and, depending on its composition, may display a core-rim structure.

Cermets are defined as TiC-based cemented carbides without WC phase. They may contain high levels of W, but usually below 50 wt.%. The microstructure is formed by carbide grains with a core-rim structure comprising TiC-rich cores and rims formed by elements such as: Ta, Nb, W, C and N. Due to the high hardness and chemical resistance provided by the carbide grains, cermets are used in high-speed applications with low feed for finish machining. Cermets possess low thermal conductivity and high thermal expansion and are therefore unsuitable for thermo-shock resistance conditions.

η-phase is a ternary carbide formed by W, Co and C of the type $(W,Co)_xC$, which forms in cemented carbides with under-stoichiometric carbon contents. η-phase has two different compositions: M_6C (stable at high temperature) or $M_{12}C$ (stable below 1150°C). The presence of large clusters of η-phase is associated with embrittlement of cemented carbides, due to the high hardness and low elastic modulus of η-phase. Finely dispersed η-phase can be used to produce dual property (DP) gradients in the mining carbide industry.

Another way of adjusting the properties of cemented carbides is through the addition of finely dispersed particles that are not formed during the sintering process and do not form part of the carbide skeleton. Whiskers (Fig. 5), super-hard particles and oxide dispersed strengtheners (ODS) have been investigated, showing interesting features that may be exploited in future industrial applications.

NbC has been investigated as a substitute for WC. NbC-based cermets, produced by conventional Powder Metallurgy techniques, have been reported to have stable elastic modulus and hardness at high temperatures. To date, NbC-based cemented carbides have exhibited lower toughness than their Co-based

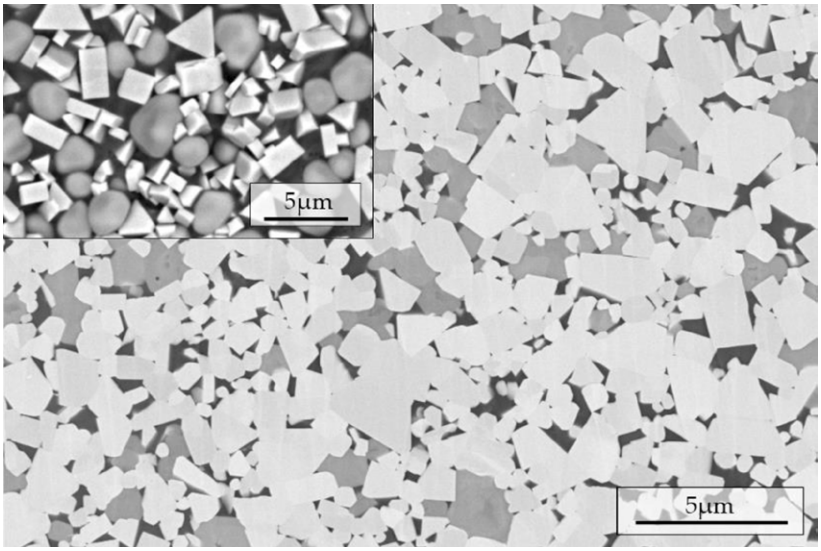

Fig. 4 SEM image of a WC-Co-γ-phase cemented carbide. SEM top surface image (left upper corner) showing the morphology of WC (white) and γ-phase (rounded grains, dark grey) [1]

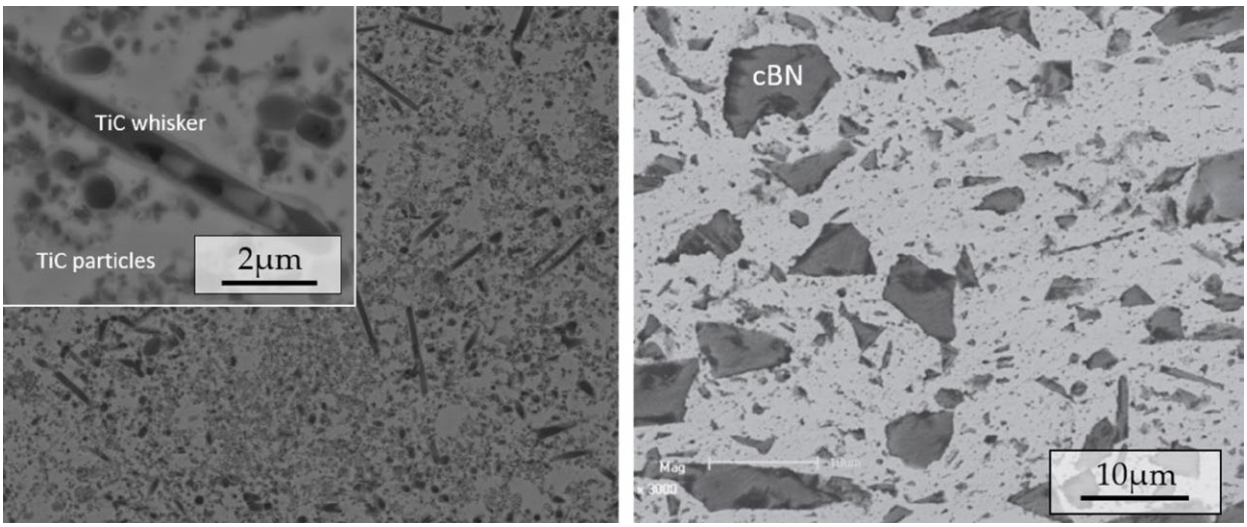

Fig. 5 SEM images of a TiC-whisker reinforced cermet (left) and ultrafine WC-VC-TaC-Ni carbide reinforced with cubic boron nitride (cBN) particles [1]

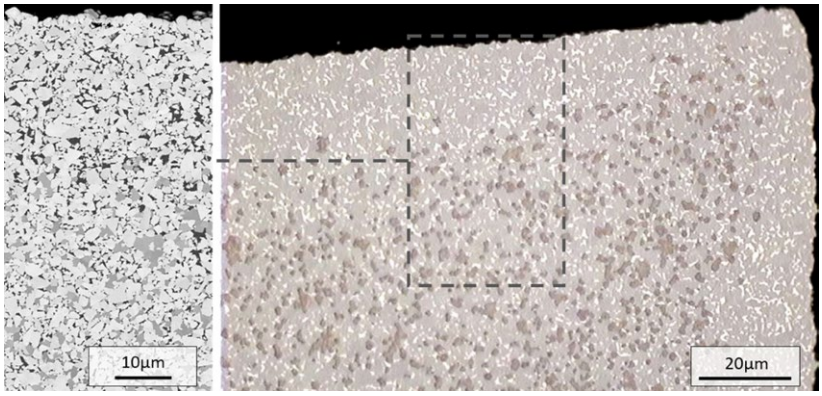

Fig. 6 LOM image of a functionally graded WC-Ti-Ta-Nb-C-N-Co cemented carbide showing a γ-phase depleted surface and the characteristic γ-phase enriched cone at the corner of the sample (right). SEM image of the corresponding magnified gradient region (WC: white phase, Co: black phase, γ-phase: grey phase) [1]

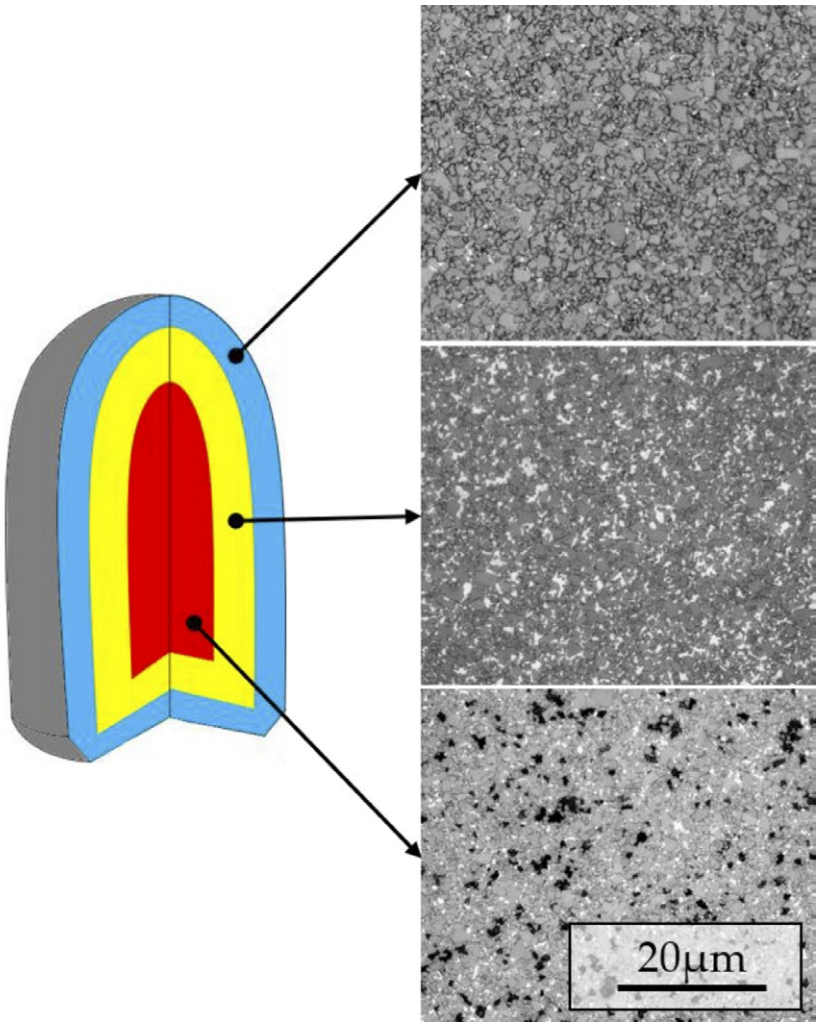

Fig. 7 Illustration of a macro-gradient cemented carbide sample with dual properties and LOM images corresponding to each of the three different zones: binder-depleted surface (blue), binder enriched rim (yellow) and η-phase containing core (red) [1]

counterparts. However, their properties make them competitive against conventional TiC-based cermets or other wear-resistant parts for applications under harsh conditions.

Functionally-graded cemented carbides

This group of cemented carbide is characterised by regions of different microstructure within a single carbide body. Functionalisation of properties is intentionally achieved by these gradients, which are formed in-situ during the sintering process. The interplay between carbide chemistry and processing allows the control of diffusion-driven mechanisms that lead to the gradient formation.

The typical cemented carbide microstructure used in steel turning is the γ-phase-free gradient. This γ-phase-free gradient (of a few µm) is formed during vacuum sintering of a nitrogen-containing cubic carbide of the type (Ti,Ta,Nb,W)(C,N). Due to the affinity of Ti and N and the fact that the vacuum sintering conditions promote degassing of the carbonitride phase, Ti (and Ta,Nb) diffuses into the core of the cemented carbide, leaving a surface region free of cubic carbonitrides and enriched in binder phase. By this method, the surface increases its toughness in comparison with the bulk, which is harder and γ-phase-containing (Fig. 6). Additionally, the diffusion process promotes the formation of the so-called "γ-phase cone" at the corner of the carbide, which contributes to the edge-line strength in tools.

γ-phase-containing cemented carbides can be nitrided to produce γ-phase-enriched surfaces of a few µm. Again, by exploiting the chemical affinity of Ti (Ta, Nb) and nitrogen, different gradient layers in thickness and composition can be produced. This concept can be exploited to improve the adhesion of carbonitride coatings or to locally improve the wear resistance of the carbide, creating a surface with enhanced chemical/wear resistance.

Cemented carbides with macro-gradients (mm size) are well established in the mining industry. The Dual

Property (DP) functionally graded carbide comprises three distinct microstructural zones: a) a surface zone with WC and reduced cobalt content with high hardness, b) an intermediate region with WC and high cobalt content with high toughness and c) a bulk containing WC, η-phase and average cobalt levels (Fig. 7). The production involves the carburisation of an η-phase-containing WC-Co cemented carbide. In the diffusion-controlled process, the high carbon activity promotes the dissolution of η-phase on the surface, producing a re-arrangement of binder distribution to form the three regions. The process also leads to a pre-load with compressive stresses of the carbide surface, which retards crack formation and propagation.

Bi-layer cemented carbides can be produced by sintering two different cemented carbide parts with distinct WC particle size, binder content and/or composition. Different hardness/toughness ratios over large volumes can be achieved with this method, allowing the production of parts with two distinct microstructures. The functionalisation of the gradient formation is based on the driving forces for Co transport, connected to the WC carbide skeleton and carbon potential of the carbide. Co will diffuse from high to low Co contents, from high to low C potentials and from coarse to fine WC skeletons. Macro-Co-gradients can be produced by carburisation of WC-Co cemented carbides, where the initial Co content is constant in all parts of the compact and the WC grain size is uniform prior to treatment. In this case, the Co-transport is dominated by the carbon potential, meaning Co will move from high to low carbon potentials. It is also possible to create a Co-enriched surface by performing a decarburisation process instead of carburisation. In both cases, the mechanical properties change along the Co gradient. The main application for this type of macroscopic gradient has, similarly to the DP gradient, been found in buttons for rock drilling. The hard and Co-depleted outer surface provides abrasion resistance and minimises the effect of erosion and corrosion of the binder phase (Fig. 8).

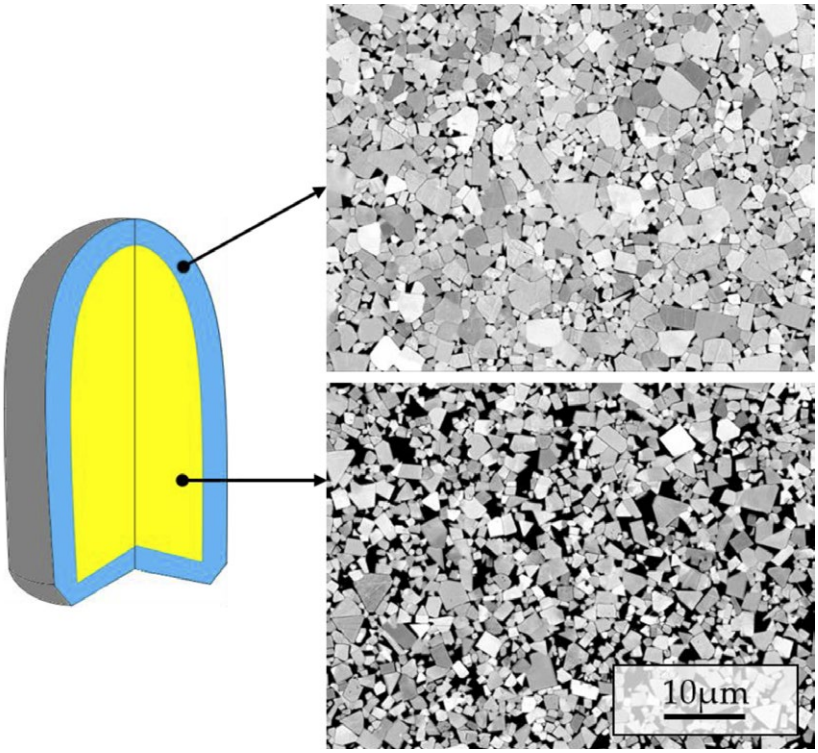

Fig. 8 Illustration of a macro-gradient cemented carbide with SEM images showing the same WC grain size and two different cobalt concentrations in the microstructure: Co-depleted surface and binder-enriched core produced by cobalt migration due to carbon potential [1]

Binder design of cemented carbides

Historically, Co has dominated the hardmetal industry. In recent years, however, extensive research has been devoted to alternative binders, due to economic, environmental, ethical and health-related issues.

Replacing cobalt with iron and/or nickel is a challenging task that has been partially achieved. Co possesses the ability to work harden through dislocation splitting, due to its low stacking fault energy. Ni and Fe do not possess this intrinsic behaviour. Nevertheless, some Fe-Ni compositions have shown potential for industrial applications in machining. Other Ni-Fe-bonded cemented carbides have been exploited in wear part applications where strong chemical attack is present. During sintering, WC grain growth is clearly affected by the binder type, showing coarser microstructures for Ni-based carbides compared with Co-based ones. Therefore, the hardness of Ni-based carbides is below Co-based counterparts for similar binder volume fractions, though Fe additions may reduce this trend.

The strength of Co binder can be enhanced by the formation of nano-precipitates of the type Co_3W. The formation of nano-precipitates in WC-Co hard metals with under-stoichiometric carbon compositions is achieved through performing heat treatments in a defined range of temperature/time. Cemented carbides with nano-precipitate-reinforced binders show enhanced strength/toughness that increases the tool life of, for instance, road hammers.

High Entropy Alloys are equi-atomic or near-equi-atomic alloys with five or more components. The use of HEA as the binder phase in cemented carbides and cermets aims at maximising their solid solution hardening and chemical stability. The main elements used so far have been

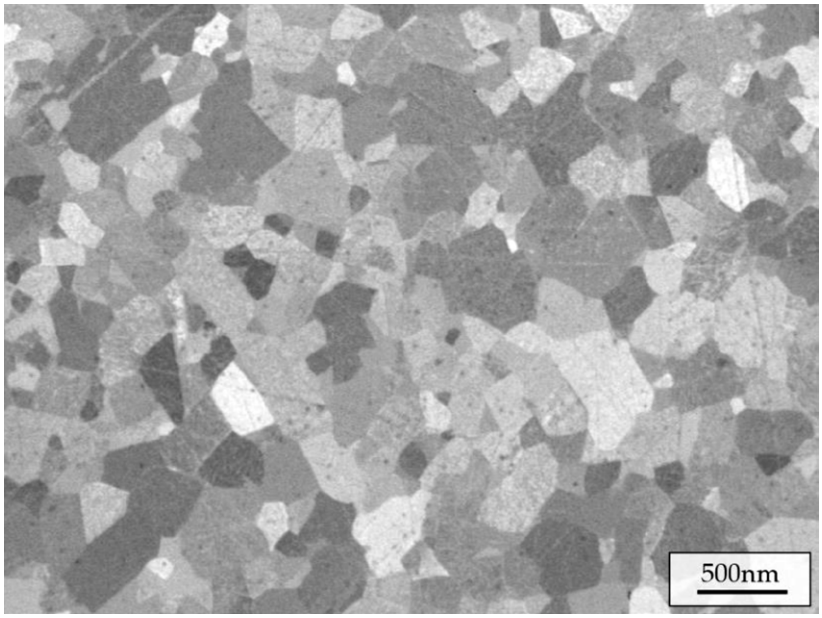

Fig. 9 Sintered microstructure of binderless WC material [1]

Fe, Ni, Co and Cr, as well as others that will dissolve in the binder during sintering, such as W. HEA materials have been produced using complicated synthesis routes, including extensive pre-milling. However, it has been proven that this is not always necessary, since the binder will melt during liquid-phase sintering, allowing for easy homogenisation.

The use of aluminides or less traditional transition metals, such as Ru, Re, Cu and Mn, in alternative binders is a current trend in the hard metal industry. Ru and Re additions to Co improve the mechanical strength of the cemented carbide without losing toughness. WC-Co-Ru cemented carbides are already established in the metal cutting industry. Research on intermetallic compounds, such as Ni_3Al or Fe_3Al, as binders has gained attention, since enhanced properties in high-temperature applications are claimed.

Finally, binder-free cemented carbides can be employed. These essentially consist only of the hard phase, i.e. WC, with no metallic binder present, except for impurities that may arise from powder processing and/or raw materials. High pressures and temperatures are needed to achieve full density, since there is no metallic binder, which may melt and distribute efficiently during the sintering process. Due to their lack in toughness, they are used in applications where resistance to abrasion and corrosion are necessary.

Following García's keynote presentation, the supporting papers in the session expanded on a number of the concepts discussed.

"The use of aluminides or less traditional transition metals, such as Ru, Re, Cu and Mn, in alternative binders is a current trend in the hard metal industry."

Challenges in the use of High Entropy Alloys as alternative binders in cemented carbides

The paper from TU Wien's Raquel de Oro Calderon, Christian Edtmaier, Wolf-Dieter Schubert and Moritz Schwingenschlögl returned to the issue of using High Entropy Alloys as alternative binders in cemented carbides and, in particular, the inherent challenges involved in using such alloys [3].

HEAs have been claimed to offer excellent hardness/toughness combinations, high hot hardness and improved corrosion resistance and it is, for this reason, that their use as substitutes for Co in WC-based cemented carbides seems very attractive. Preliminary work in the field has reported remarkable properties for cemented carbides prepared from WC powders and HEAs, where the HEAs used are mainly based on the system FeNiCoCuCr. However, recent studies carried out by the TU Wien team have shown that phase formation in systems containing high amounts of Cr must be treated with care. The high C-affinity of Cr leads to the formation of Cr-rich carbides that might be detrimental to the Transverse Rupture Strength (TRS) of these materials. It needs to be considered that, when high Cr contents are used, a significant amount of binder phase is substituted by a carbide phase.

When considering the use of alternative binders, not only are the properties of the binder itself important, but also the interaction between the binder phase and the hard phase used (in this case WC). The reported work was aimed at providing an overview of the phase formation in WC-based cemented carbides with multi-component binders. Starting from an FeNiCo binder, different additions of Cu or Cr were considered, in order to determine the maximum amount of these elements that could be dissolved in the binder without forming secondary phases. Also, Cr additions to an FeNiCoCu binder was considered.

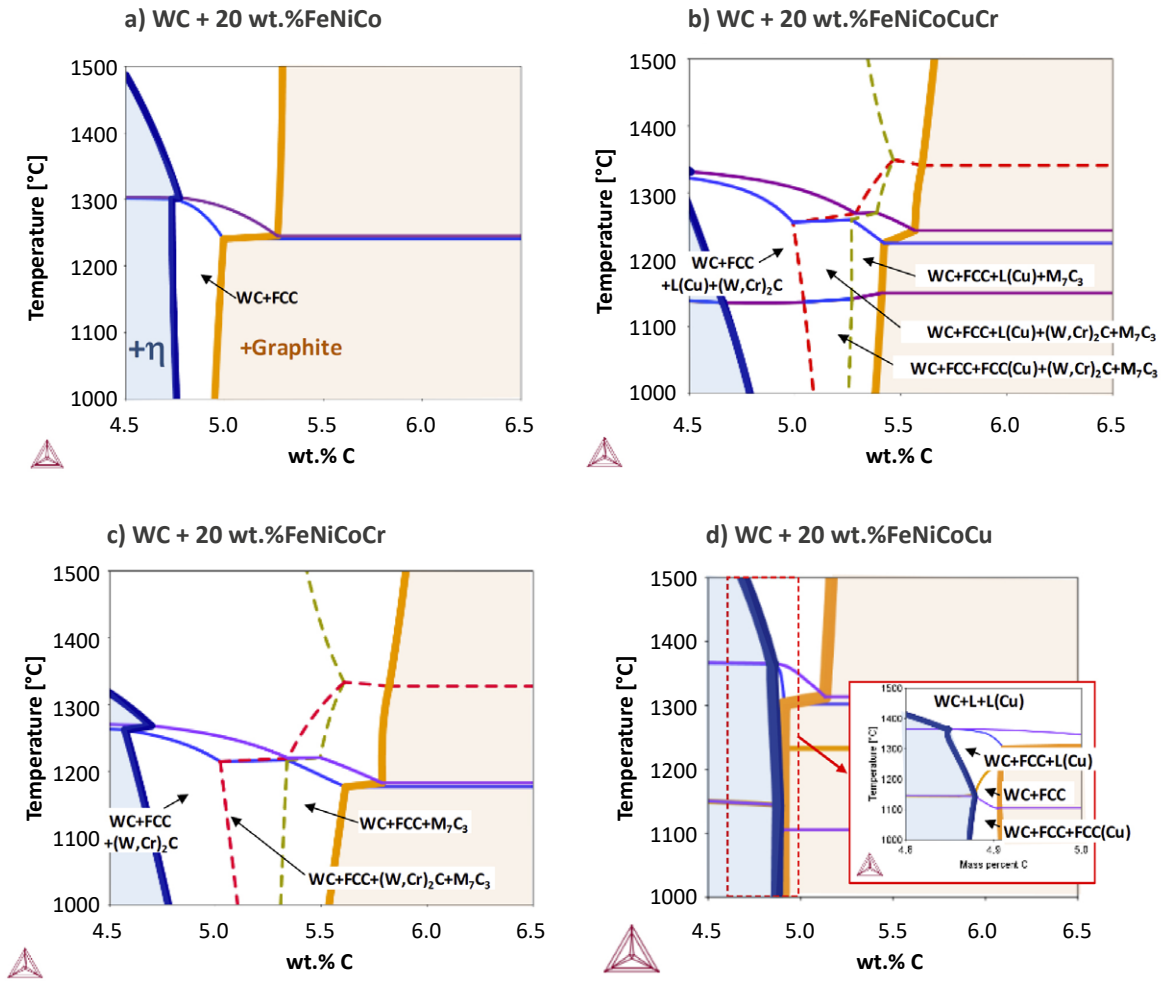

Fig. 10 Isopleth T vs wt.% C of the system WC-20 wt.% Binder at carbon contents between 4.0 and 6.5 wt.% C. Binders: a) FeNiCo, b) FeNiCoCuCr, c) FeNiCoCr, d) FeNiCoCu. Calculated with the software ThermoCalc using the database TCFE 9 [3]

The study was based on a theoretical assessment of these systems, the use of the commercial thermodynamic software tool ThermoCalc, and an experimental study in which samples with different compositions were analysed using SEM and X-Ray Diffraction (XRD) techniques.

For the preparation of the samples, selected amounts of the powders WC, Co, Ni, Fe, Cu were mixed and heated up in an induction furnace at 1460°C for 20 minutes under an argon atmosphere. The cooling rate was rather high in the induction furnace and samples could be taken out from the furnace approximately 45 minutes after the end of the holding period. Fig. 10 shows the isopleths T vs wt.%C for cemented carbides containing WC+20wt.% binder, with different binder compositions. Fig. 10(a) corresponds to a simple three-component FeNiCo equi-atomic binder, Fig. 10(b) presents a typical five-component HEA composition FeNiCoCuCr (equi-atomic), while Fig. 10(c) and Fig. 10 (d) present four-component binders with FeNiCoCr and FeNiCoCu.

While the system with a three-component binder looks relatively simple, presenting a two-phase area where only WC+FCC phases are stable, in the five-component binder (FeNiCoCuCr), no two-phase area could be found. In this latter case, in the region free of η-carbides and graphite, WC and FCC phases always co-exist with Cr-rich carbides and with a second FCC phase, which is Cu-rich. The particular challenges of using elements such as Cr and Cu in the multi-component alloy can be very clearly recognised when looking at the 4-component binders presented in Fig. 10(c) and Fig. 10(d). In the case of the FeNiCoCr alloy (Fig. 10(c)), the high amount of Cr in the binder gives rise to the formation of Cr-carbides all over the carbon window (region free of η-carbides and graphite). On the other hand, the use of Cu in the binder narrows the carbon window and might lead to the formation of a second Cu-rich FCC phase with a lower melting temperature.

In order to analyse the solubility limits of Cu and Cr in the multi-component binder, ThermoCalc was

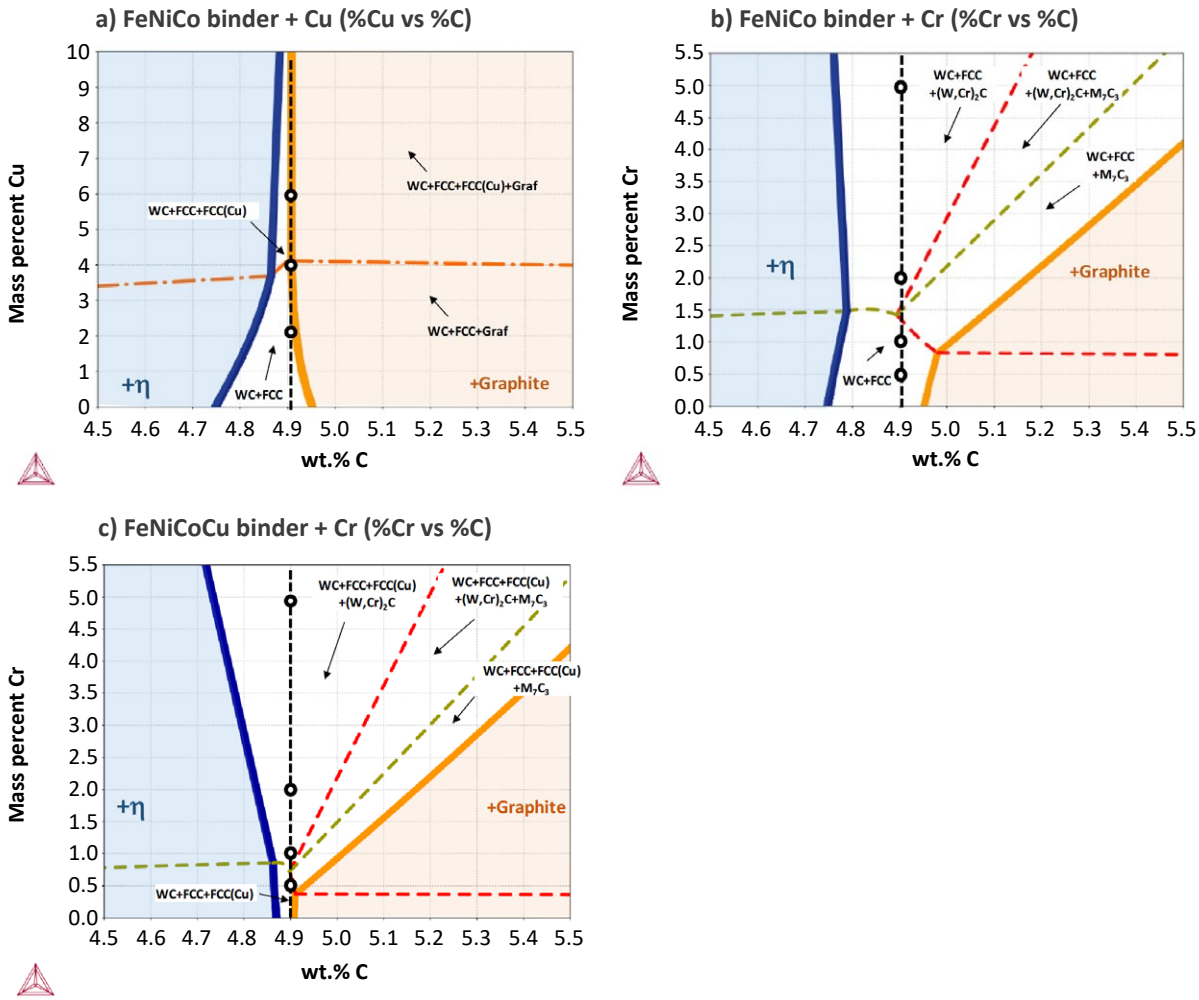

Fig. 11 Phase diagrams at 1000°C. a) WC-FeNiCo binder with additions of Cu, wt.%Cu vs wt.%C, b) WC-FeNiCo binder with additions of Cr, wt.%Cr vs wt.%C, c) WC-FeNiCoCu binder with additions of Cr, wt.%Cr vs wt.%C. Dashed line shows the stoichiometric composition used in this work. The dots in the line indicate the samples produced experimentally [3]

used to predict the stable phases at 1000°C, considering different C contents and increasing additions of Cu in FeNiCo binder (Fig. 11(a)), Cr in FeNiCo binder (Fig. 11(b)) and Cr in FeNiCoCu binder (Fig. 11(c)). The dashed line at 4.9 wt.% corresponds to the stoichiometric carbon content used in the study. The different spots drawn on the line represent the compositions that were experimentally studied.

In the FeNiCo binder with Cu additions (Fig. 11(a)), the diagram suggests that a total addition of 4 wt.% Cu (which corresponds to a binder with 20 wt.% Cu) would present the maximum solubility of Cu in the binder phase. At a 6 wt.% Cu addition (equivalent to 30 wt.% Cu in the binder), the maximum solubility would be exceeded and segregation of Cu-rich second phase should be found. EDS mapping of samples with such compositions were in excellent agreement with the theoretical calculations. While a homogeneous distribution of Cu in the binder is found with 2 wt.% and 4 wt.% Cu (10 wt.% and 20 wt.% in the binder respectively), a Cu-rich phase segregates around the WC particles with a 6 wt.% Cu addition. EDS point analyses on the binder phase were used to determine the amount of Cu actually dissolved in the binder phase (see Table 1). The amount of Cu measured in the binder is always below the expected value, which might be due to evaporation of Cu at the high temperatures used for melting the alloys. At the highest Cu addition, the actual amount of Cu in the binder (18 wt.%) is close to the solubility limit calculated theoretically (20 wt.%) and far from the amount of Cu in the binder that corresponds to the addition of 6 wt.% Cu (30 wt.% Cu in the binder). This suggests that, at such high additions, the solubility limit of Cu in the binder is exceeded, causing the segregation of a secondary Cu-phase.

In the case of FeNiCo binders with Cr additions, the phase diagram in Fig. 11(b) suggests that the sample with a 1% Cr addition (5 wt.% Cr in the binder) should still be within the two-phase area WC + FCC, while the samples with 2 wt.% Cr (10 wt.%

Cr in the binder) would exceed the solubility of Cr in the binder phase, causing the precipitation of Cr-rich carbides. This was confirmed by EDS mapping. While the sample with 1% Cr showed only WC and FCC phase with Cr evenly distributed in the binder, the sample with 2 wt.% Cr addition (10 wt.% Cr in the binder) showed Cr-rich areas that corresponded to Cr-rich carbides. The amounts of Cr measured in the binder phase were in very good agreement with these findings (Table 2). Up to 2 wt.% Cr addition (10 wt.% Cr in the binder), the amount of Cr measured in the binder phase was quite close to the amount of Cr corresponding to the respective additions. This suggests the maximum solubility of Cr in an FeNiCo binder is below 10 wt.%. For higher additions of Cr (see sample with 5 wt.% Cr total addition- 25 wt.% Cr in the binder), the amount of Cr present in the binder was around the defined solubility limit (~10 wt.% Cr) and the remaining Cr was present in the form of Cr-rich carbides.

In the case of FeNiCoCu binders with Cr additions, the phase diagram in Fig. 11(c) suggests that the sample with 0.5 wt.%Cr addition (2.5 wt.% Cr in the binder) would be within the region free of Cr-carbides, while the sample with 1 wt.% Cr addition (5 wt.% Cr in the binder) could already show formation of Cr carbides. According to the phase diagram, all samples should present the formation of a secondary Cu-rich FCC phase. These findings were also confirmed experimentally. For both 0.5 wt.% and 1 wt.% Cr additions, EDS mapping showed the presence of a Cu-rich phase, as expected from the phase diagram. Also, while the sample with 0.5 wt.% Cr (2.5 wt.% Cr in the binder) showed a homogeneous distribution of Cr in the binder phase, the sample with 1 wt.% Cr addition (5 wt.% Cr in the binder) showed the incipient formation of Cr-rich carbides. Again, EDS point analyses were in quite good agreement with these findings (see Table 3). For the samples containing high Cr additions (2 and 5 wt.%, corresponding to 10 and 25 wt.% Cr in the binder respectively), the amount of Cr measured in the binder was around 8 wt.% and the remaining Cr formed Cr-rich carbides. The amount of Cr measured in these samples (8 wt.%) was slightly above the theoretical solubility limit, which, according to the phase diagram, should be around 5 wt.%. It was suggested that this could be partly due to the relatively high cooling rates that might allow a slight increase in the amount of Cr 'trapped' in the binder phase.

Phase formation in the different systems studied was confirmed through XRD assessments. Formation of a secondary FCC Cu-phase is difficult to identify with XRD, as it only causes a broadening of the FCC peaks. The types of Cr-rich carbides formed are more easily identified in the sample with higher Cr contents. Fig. 12 shows the XRD pattern of the sample with FeCoNiCu binder with 5 wt.% Cr addition (25 wt.% Cr in the binder). This composition would correspond to the equi-atomic binder FeNiCoCuCr. The XRD pattern indicates the presence of Cr rich carbides of the sub-carbide type, i.e. $(W, Cr)_2C$. Sub-carbides with different Cr contents are identified in the pattern. Besides WC, FCC phase and Cr-rich sub-carbides, η- carbides are also found in this sample.

It was concluded from these findings that the typical FeNiCoCuCr does not seem to be a viable option for the substitution of Co as a binder in WC-based cemented carbides, on the one hand, due to the formation of Cu-rich phases and Cr-rich carbides, and, on the other hand, because the composition of the binder phase would be far away from the theoretical composition of the HEA.

Total Cu addition (wt.%)	2	4	6
Corresponding Cu in binder (wt %)	10	20	30
EDS measured Cu in binder (wt %)	7.5	15	18

Table 1 Summary of experimental amounts of Cu in FeCoNi binders, at different Cu additions. The total Cu addition corresponds to the WC+20 binder mix, while the corresponding amount of Cu in the binder is calculated considering only the composition of the binder phase [3]

Total Cr addition (wt.%)	0.5	1	2	5
Corresponding Cr in binder (wt %)	2.5	5	10	25
EDS measured Cr in binder (wt %)	2	5	9	10

Table 2 Summary of experimental amounts of Cr in FeCoNi binders, at different Cr additions. The total Cr addition corresponds to the WC+20 binder mix, while the corresponding amount of Cr in the binder is calculated considering only the composition of the binder phase [3]

Total Cr addition (wt.%)	0.5	1	2	5
Corresponding Cr in binder (wt %)	2.5	5	10	25
EDS measured Cr in binder (wt %)	2	5	8	8

Table 3 Summary of experimental amounts of Cr in FeCoNiCu binders, at different Cr additions. The total Cr addition corresponds to the WC+20 binder mix, while the corresponding amount of Cr in the binder is calculated considering only the composition of the binder phase [3]

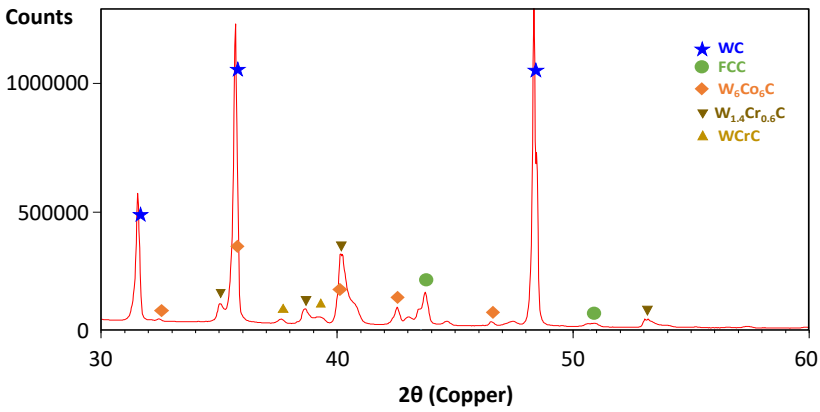

Fig. 12 XRD pattern of the sample WC-20 Binder: FeCoNiCu with addition of 5 wt.%Cr (equivalent to a binder FeCoNiCu- 25 wt.%Cr). The pattern shows WC, FCC phase, eta phase Fe_3W_3C and sub-carbides $Cr_{0.5}W_{0.5}C_{0.5}$ and $Cr0_{.3}W_{0.7}C_{0.5}$ [3]

Effect of Ni content on microstructure and mechanical properties of NbC-WC-Ti(C0.7,N0.3)-Ni cermets

Next, a paper from Shuigen Huang, J Vleugels, J H Huang, B Lauwers and J Qian (KU Leuven, Belgium), H Mohrbacher (NiobelCon bvba, Belgium), J Sukumaran and P De Baets (Ghent University, Belgium), E Cannizza (EHT-Engineering Consulting, Brazil) and M Woydt (MATRILUB, Germany) addressed the effect of Ni content on microstructure and mechanical properties of NbC-WC-Ti($C_{0.7}$,$N_{0.3}$)-Ni cermets [4].

As a high-hardness refractory carbide, NbC is rarely explored as a matrix carbide, although its physical and chemical properties show a high potential for wear and tribological applications. Pure NbC, as well as metal-bonded NbC, have been reported to have a pronounced wear resistance under dry sliding conditions versus other monolithic ceramics and carbides and have also generated an increased tool life when compared with WC-Co inserts. For successful turning operations, it has been concluded that NbC-based cermets should exceed a HV_{30} of 1400 kg/mm^2 and possess a high bending strength. Additions of secondary carbides/nitrides also have a significant impact on the microstructure and mechanical properties of NbC-based materials. There is, however, no information available on the influence of the Ni binder content on the microstructure and mechanical properties of NbC-based cermets. In the reported study, NbC-xNi-18WC-14Ti($C_{0.7}$,$N_{0.3}$) cermets with Ni content ranging from 6 to 20 wt.% were processed to obtain NbC-Ni based cermets with refined ceramic grains and tailored mechanical properties for wear-resistant applications.

NbC (FSSS=1.52 µm), Ti($C_{0.7}$,$N_{0.3}$) (FSSS = 3.0 µm), WC (FSSS = 2 µm) and Ni (FSSS = 3-7 µm) powders were used to prepare the NbC cermets. The NbC powder had total C and O contents of 11.2 and 0.17 wt.% respectively. The primary NbC grain size was in the sub-micron range. The Ti($C_{0.7}$,$N_{0.3}$) powder consisted of both sub-micron and 5-10 µm sized particles. The chemical compositions of the investigated NbC cermets with different Ni contents are summarised in Table 4. The theoretical density was calculated on the basis of the rule of mixtures.

All powder mixtures were prepared in a multi-directional mixer in ethanol for 48 h using WC-6 wt.% Co milling balls. The suspensions were dried in a rotating evaporator at 65°C. Cold isostatically pressed (200 MPa) powder compacts were pressure-less sintered for 90 min at 1390 and 1450°C in vacuum (~20 Pa) at a heating rate of 3°C/min in a graphite furnace.

Fig. 13 shows the backscattered electron (BSE) contrast micro-structures of the 6Ni grade cermet, sintered for 90 min at 1390°C (Fig. 13(a)), and the cermets sintered for 90 min at 1450°C (Figs. 13(b-f)).

Only two contrast phases, i.e. bright NbC-based carbide grains and a darker Ni-based binder, were detected in the cermets sintered at 1450°C, whereas a few dark contrast Ti(C,N)-rich grains were observed in the cermet sintered at 1390°C. All sintered cermets were fully densified, regardless of the Ni content. These cermets exhibited clear core/rim structured carbonitride grains. Due to the lower atomic mass of Ti compared with Nb or W, the darker rim is richer in Ti, whereas the bright cores have a higher W and Nb concentration. Basically, a Ti-rich (Nb,W,Ti)(C,N) solid solution was formed around the Nb-rich (Nb,W,Ti)(C,N) grains. W was detected both in the rim and the core, as well as in the Ni binder. The formation of a Nb-rich core structure was

Grade	Ni content (wt.%)	Composition (wt.%)	Theoretical density (g/cm^3)
6Ni	6	NbC-6Ni-18WC-14Ti($C_{0.7}$,$N_{0.3}$)	8.01
9Ni	9	NbC-9Ni-18WC-14Ti($C_{0.7}$,$N_{0.3}$)	8.04
12Ni	12	NbC-12Ni-18WC-14Ti($C_{0.7}$,$N_{0.3}$)	8.07
16Ni	16	NbC-16Ni-18WC-14Ti($C_{0.7}$,$N_{0.3}$)	8.12
20Ni	20	NbC-20Ni-18WC-14Ti($C_{0.7}$,$N_{0.3}$)	8.16

Table 4 Chemical compositions of the investigated NbC-Ni based cermets [4]

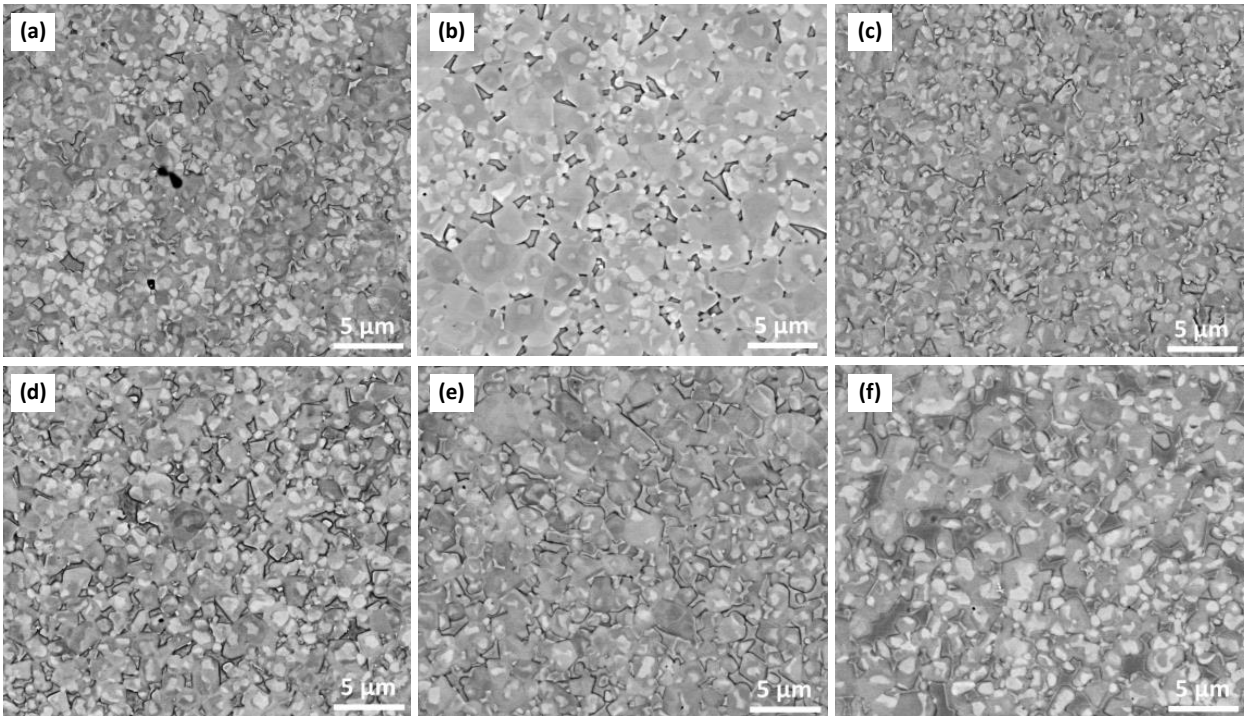

Fig. 13 Backscattered electron micrographs of NbC-Ni based cermets. (a) 6Ni sintered at 1390°C, (b) 6Ni sintered at 1450°C, (c) 9Ni sintered at 1450°C, (d) 12Ni sintered at 1450°C, (e) 16Ni sintered at 1450°C and (f) 20Ni sintered at 1450°C [4]

attributed to the higher surface energy of NbC as compared with Ti(C,N). The cores of the undissolved NbC grains acted as nucleation sites for the rim structure. With the interdiffusion of Ti and W, the core of the grains formed a Nb-rich (Nb,W,Ti)(C,N) mixed carbide, together with a Ti-rich rim. The overall surface energy of the cermets was therefore decreased when the Ti-rich (Nb,W,Ti)(C,N) rim was formed on the NbC core.

XRD phase analysis indicated that all the cermets sintered at 1390°C and 1450°C contained a FCC solid solution Ni binder and a cubic NbC solution phase. The NbC-based solid solution (Nb,Ti,W)(C,N) phase had the same crystal structure as the cubic NbC phase. Due to the very close compositional match of the rim and core areas, XRD analysis did not allow a differentiation of their individual peak positions. Fig. 14(a) shows the change in lattice parameters of the NbC solution and binder phases as a function of the Ni content. Both the lattice parameter of the NbC solution phase and of the Ni binder decreased with increasing Ni content. Since the atomic radius of W (139 pm) and Ti (144.2 pm) are smaller than for Nb (146 pm), the cubic lattice parameter of the NbC phase decreased with increasing amounts of solid solution alloying elements. The change of the NbC phase lattice parameter can be explained by the calculated phase composition, as presented in Figs. 14(b-d). At 1450°C, mainly two phases, i.e. NbC solution and liquid Ni binder, were predicted in the cermets with 6 to 20 wt.% Ni, as seen in Fig. 14(b). With increasing Ni content, more and more NbC was replaced with Ni, resulting in an increased concentration of WC and TiC in the NbC solution phase. The NbC solution phase had a very low TiN content, as shown in Fig. 14(c). The lattice parameter of the binder phase was mainly influenced by the dissolution of alloying elements. With increasing Ni content, the concentration of WC in the Ni binder decreased, whereas the TiC and NbC contents remained low and constant, as shown in Fig. 14(d) Therefore, the lattice parameter of the Ni binder was also decreased, since the atomic radius of Ni (124.6 pm) is lower than for W (139 pm).

Vickers hardness, indentation fracture toughness and three-point flexural strength of the cermets are shown in Fig. 15. With increasing Ni content, the hardness decreased, whereas the fracture toughness increased almost linearly for the cermets sintered at 1390°C or 1450°C. Sintering at 1450°C reduced the hardness and increased the toughness compared with the equivalents sintered at 1390°C. The 9Ni (NbC-9Ni-18WC-14Ti($C_{0.7}$,$N_{0.3}$)) cermet, sintered at 1450°C, exhibited a good combination of hardness (1500 kg/mm^2) and indentation toughness (~ 8.8 MPa.m$^{1/2}$), as well as a three-point flexural strength of 2000 MPa. The crack propagation path originating from the corners of Vickers indentations of the 20Ni cermet, sintered at 1450°C, is shown in Fig. 15(d). Multiple crack paths were present, i.e., cracks propagated through NbC grains, along the NbC/NbC grain boundaries, along the NbC/Ni interface and through the binder. Intergranular fracture along the NbC/Ni and NbC/NbC grain boundaries were the major crack fracture mode at a high Ni content,

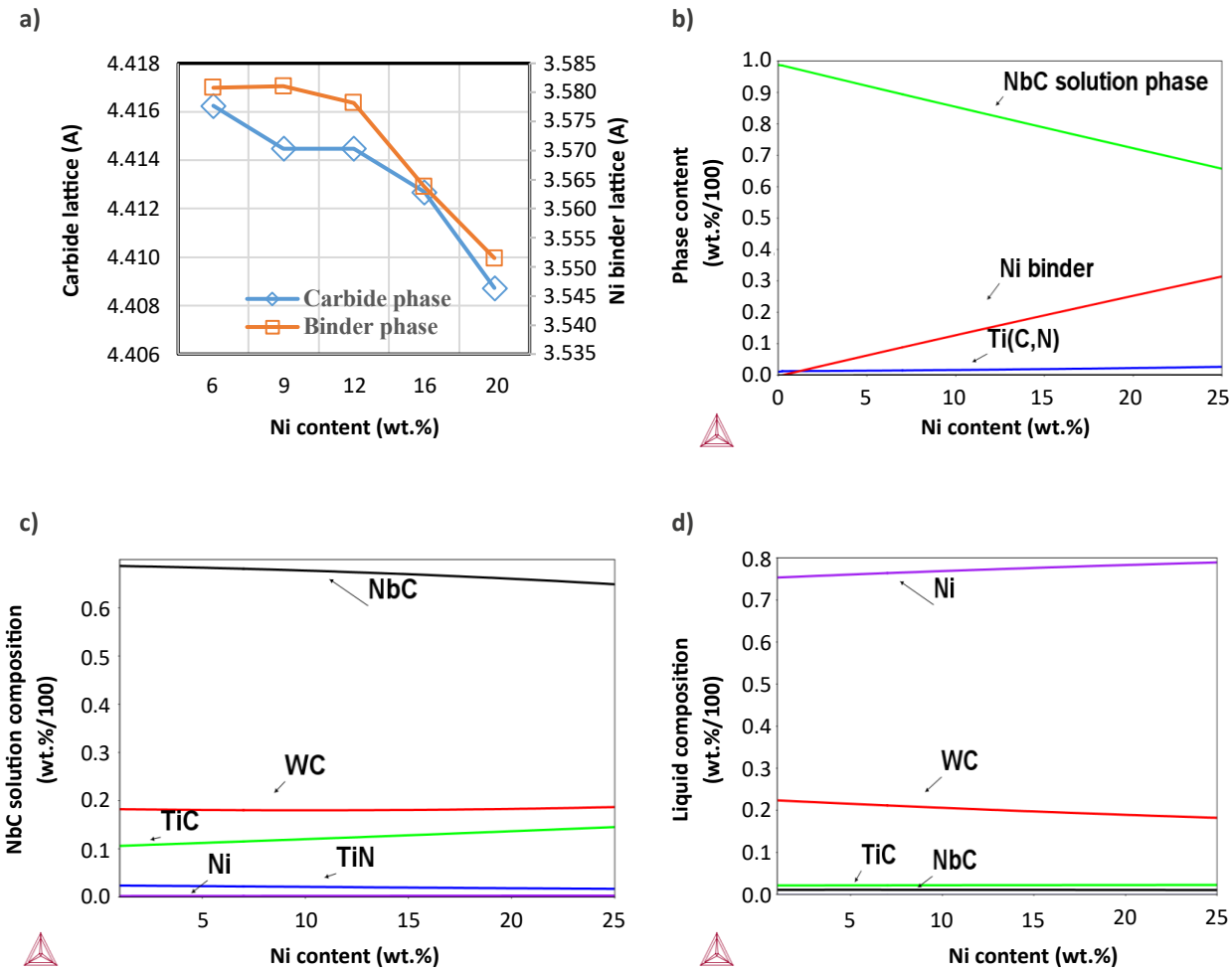

Fig. 14 Influence of the Ni content on the lattice parameter of the NbC solution and binder phase in the NbC-Ni based cermets (a) and thermodynamically estimated phase constitution (b) and chemical composition of the NbC solution phase (c) and Ni binder phase (d) at 1450°C [4]

indicating that crack deflection is a major toughening mechanism, besides crack bridging by the Ni binder. The crack deflection contribution and binder bridging effect were decreased in a 6 wt.% Ni cermet, due to the lower amount of NbC/Ni interfaces.

Microstructure and properties of WC-Co hardalloys with Ru addition

Finally, the paper from Kaihua Shi, XiuQi Zan and XinYu Yang (Zigong Cemented Carbide Corp. Ltd, China) considered the microstructure and properties of WC-Co hard metals with Ruthenium (Ru) additions [5].

Cemented carbides, alloyed with the noble metals Ru, Rh, Pd, Re, Os and Ir, are highly wear- and corrosion-resistant and can be used in aggressive and abrasive media. Furthermore, these materials can be used successfully for the manufacture of tools for applications subject to particularly severe conditions, for example the turning and milling of tungsten, heat-resistant alloys and special steels.

Previous studies on ruthenium additions in WC-Co hard metals have been mainly focused on improving corrosion resistance and certain mechanical properties, without much attention being paid to the effects of ruthenium on thermal behaviour.

The main purpose of the reported study was to extend this previous work by focusing on the influence of Ru addition on the microstructure, mechanical properties and thermal behaviour of WC-Co hard metal.

WC, Co and Ru powders were mixed in a rolling ball mill for 30 h, using WC-6 wt.%Co balls with a diameter of 6.35 mm as grinding media, to produce the compositions of WC-10Co-xRu shown in Table 5. The ratio of grinding media to powder was 4:1 and the rotational speed was 80 rpm. After ball milling, the slurries were dried in a 60°C oven for 60 min to obtain the powders for pressing. The powders were then pressed into green compacts with a radius of 25 ± 0.5 mm and a thickness of 4 ± 0.5 mm using a pressure of 180 MPa, for thermal property tests. Rectangular specimens of 6.50 ×

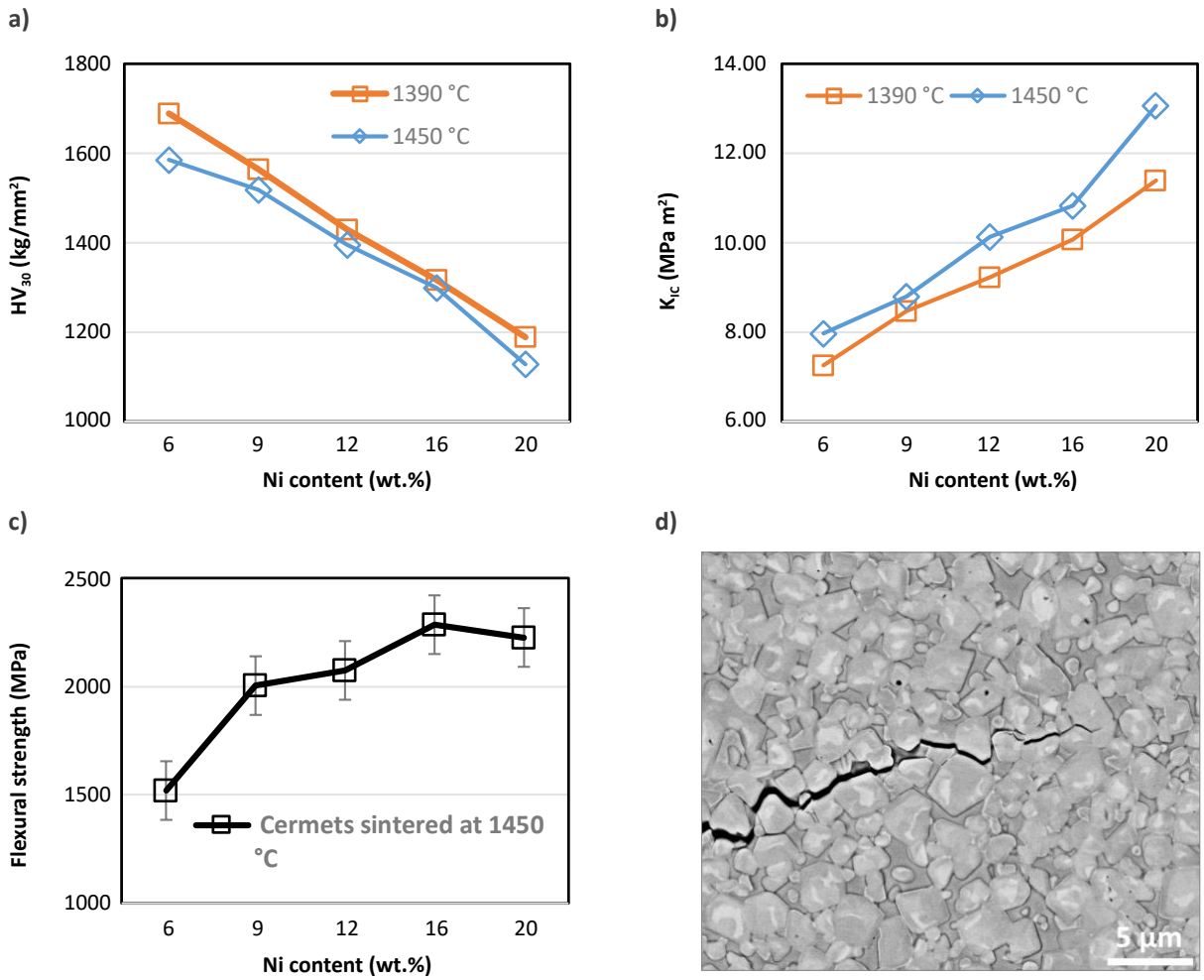

Fig. 15 Influence of Ni binder content on the hardness (a), fracture toughness (b) and three-point flexural strength (c) of the NbC-Ni based cermets. Indentation crack propagation pattern of the NbC-20Ni-18WC-14Ti($C_{0.7}$,$N_{0.3}$) (wt.%) cermet sintered at 1450°C (d) [4]

5.25 × 20.00 mm and 57 × 26 × 6 mm in dimension were also pressed for bending strength and abrasive wear resistance tests. All the samples were placed on a graphite tray and sintered in an industrial-scale HIP furnace with a maximum sintering temperature of 1430°C for a dwell time of 90 min. During the last 15 min at maximum sintering temperature, an isostatic pressure of 5 MPa was applied to the samples using argon.

Fig. 16(a-g) shows the micrographs of the samples after sintering. It can be seen in these figures that the abnormal growth of WC grains tends to decrease with increasing Ru additions. SEM assessments of fracture surfaces of the samples after sintering found abnormal growth grains to be fracture sources of the alloys due to their transgranular fracture mechanism. However, with increasing Ru content, WC grains tend to be more homogeneous and intergranular fracture gradually becomes the dominant mechanism.

In relation to the resultant mechanical properties, the relationship between Rockwell hardness and transverse fracture toughness of the samples after sintering was as shown in Fig. 17. The hardness and tough-

Sample No.	Co (%)	Ru (%)	WC
1	10	0	Balance
2	10	0.2	Balance
3	10	0.5	Balance
4	10	0.8	Balance
5	10	1.0	Balance
6	10	1.5	Balance
7	10	2.0	Balance

Table 5 Chemical compositions of WC-10Co-xRu powder mixtures [5]

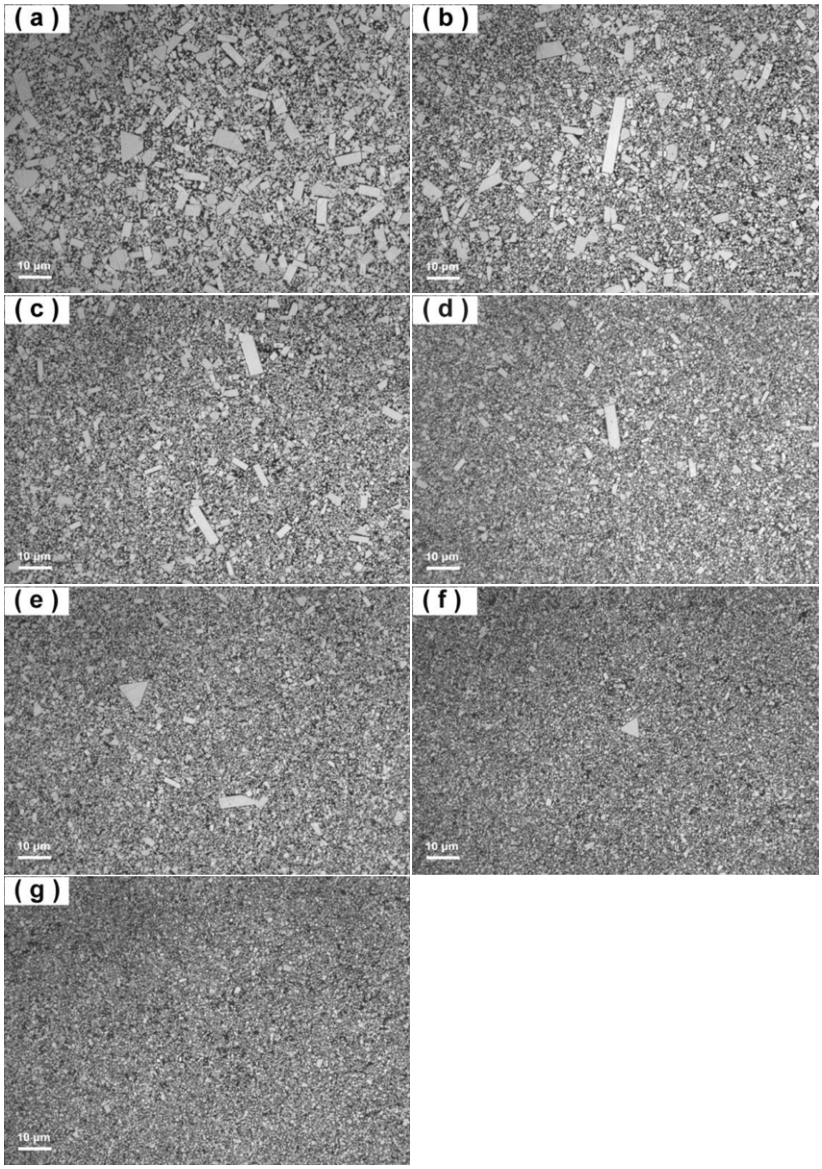

Fig . 16 Micrographs of the samples after sintering: (a) Sample 1, (b) Sample 2, (c) Sample 3, (d) Sample 4, (e) Sample 5, (f) Sample 6, (g) Sample 7 [5]

ness of the samples were clearly improved by the addition of Ru. Moreover, in contrast to the effect of grain growth inhibitor additions (Cr_3C_2, VC, etc.), which increase hardness but reduce toughness, Ru additions increase hardness and toughness simultaneously. Ru additions will only inhibit abnormal grain growth, rather than refine the general WC grain structure. The hardness of the WC-based alloys will be enhanced by the solid solution strengthening of Ru in Co and the toughness will also be improved by the decreasing proportion of transgranular fracture resulting from the decreasing level of abnormal grain growth.

In relation to thermal properties, the effects of Ru additions on thermal conductivity, thermal diffusion coefficient and heat capacity of the base alloy are illustrated in Figs. 18 and 19, respectively. It is clear in Fig. 18 that, with an increase in the Ru content, thermal conductivity and thermal diffusion coefficient of the cemented carbides decrease gradually. However, it can be seen in Fig. 19 that there is no regular change in heat capacity with an increase in the Ru content.

It is believed that the more complex the crystal structure, the greater the degree of anharmonicity of lattice vibration will be; reducing phonon free path and thus leading to a decrease of thermal conductivity. In addition, crystal defects, grain boundaries and impurities will decrease the phonon free path, thus decreasing the thermal conductivity. Ru additions could make the crystal structure and the chemical composition more complex and increase grain boundary area by reducing abnormal WC growth, thus leading to a decrease of thermal conductivity.

In Fig. 18, it is clear that the thermal diffusion coefficient changes as a function of Ru content in a similar manner to thermal conductivity. It is known that the thermal diffusion coefficient is mainly affected by three factors: thermal conductivity, heat capacity and density. The variation of heat capacity of the seven samples has been found to be not statistically significant (Fig. 19). Also, the densities of the cemented carbides were quite similar. As a result, with increasing Ru addition, the thermal diffusion coefficient decreases in a similar manner to thermal conductivity.

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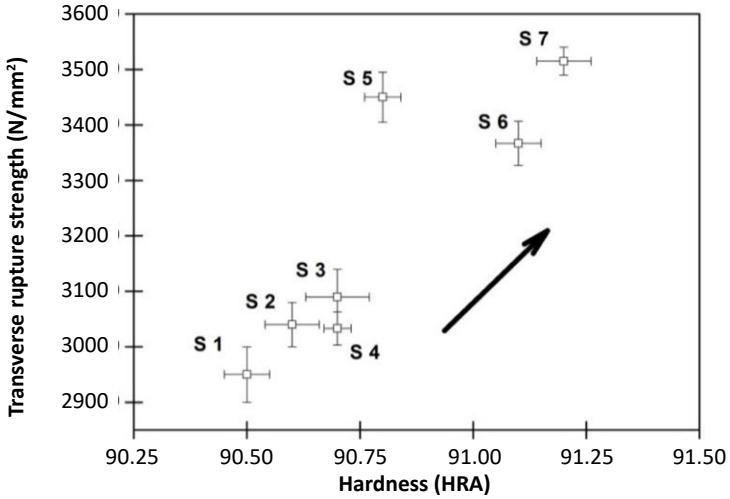

Fig. 17 Relationship between Rockwell hardness and Transverse fracture toughness. (S1) Sample 1, (S2) Sample 2, (S3) Sample 3, (S4) Sample 4, (S5) Sample 5, (S6) Sample 6, (S7) Sample 7 [4]

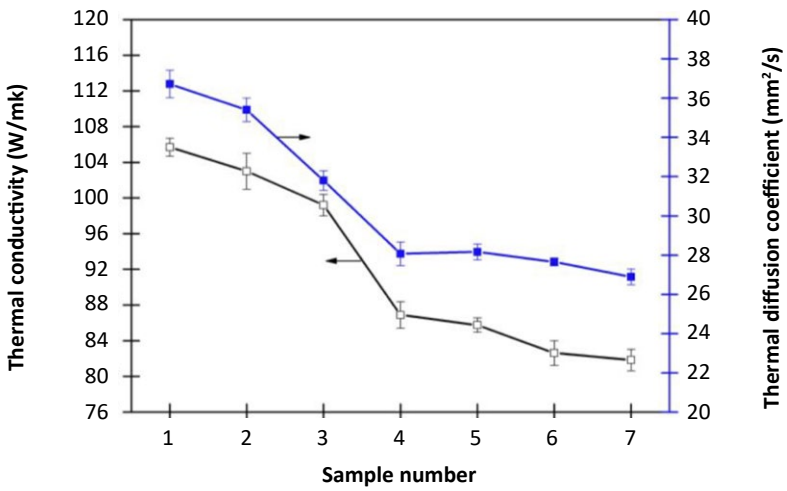

Fig. 18 Thermal conductivity and thermal diffusivity of the sintered cemented carbides [4]

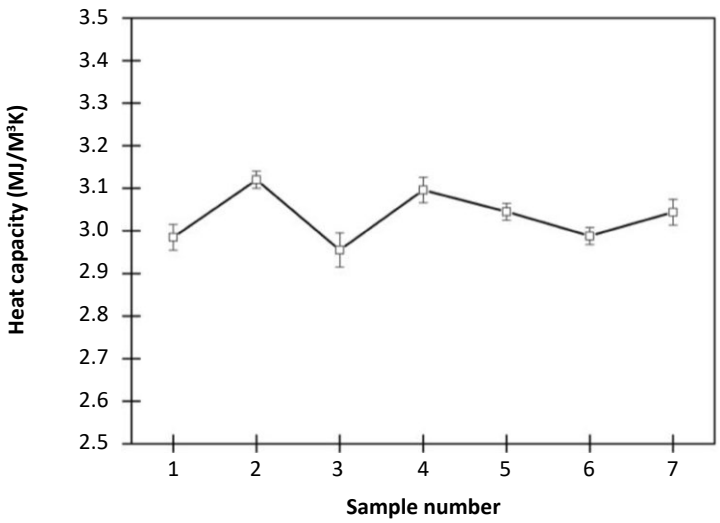

Fig. 19 Heat capacity of the sintered cemented carbides [4]

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