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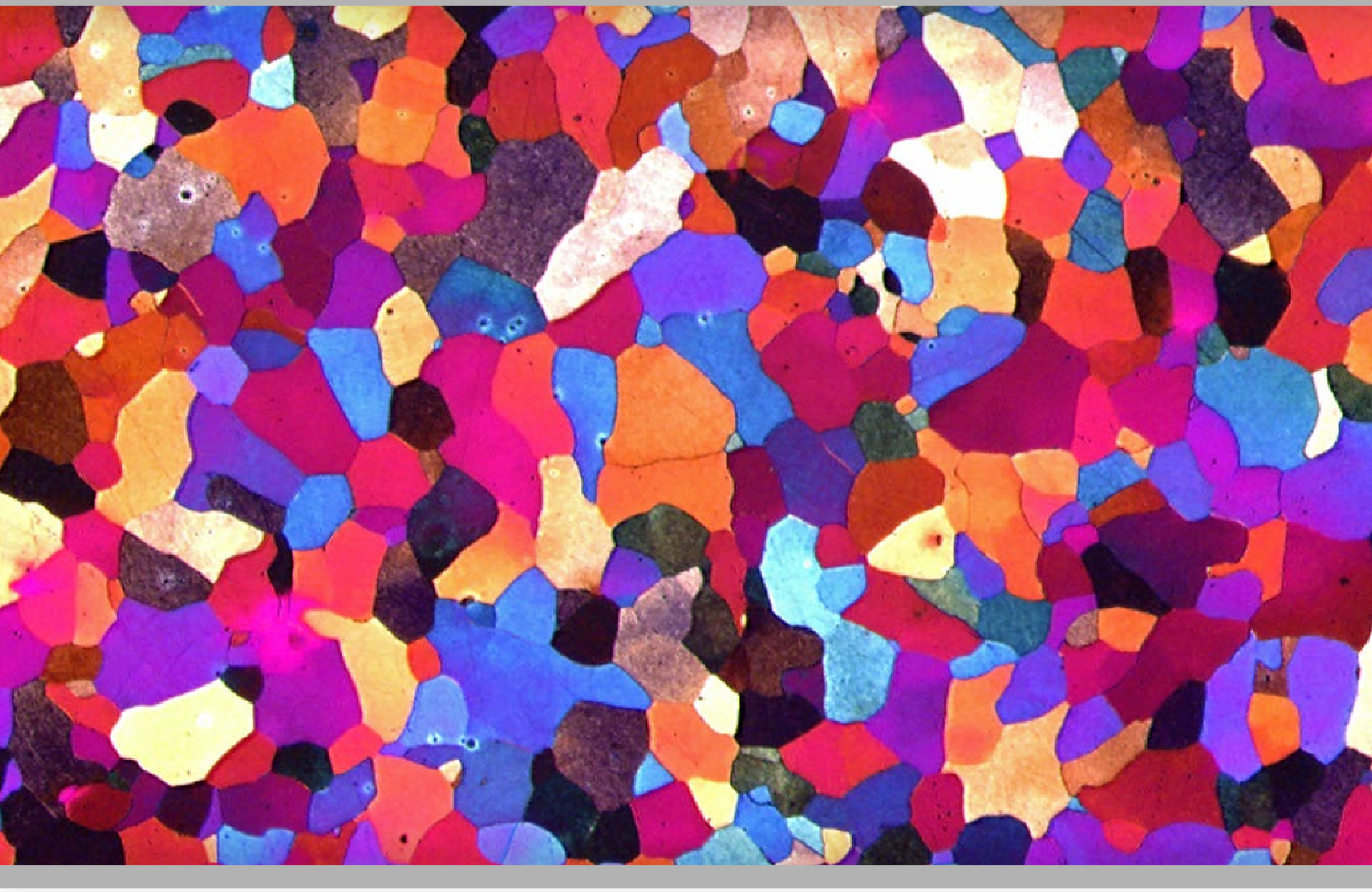
POWDER METALLURGY REVIEW



METALLOGRAPHY FOR PM, PART 2

COMPANY VISIT: TOZMETAL

DEFECT DETECTION IN GREEN COMPACTS

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Publisher & editorial offices
Inovar Communications Ltd
2 The Rural Enterprise Centre
Battlefield Enterprise Park
Shrewsbury SY1 3FE
United Kingdom

Editor & Publishing Director
Paul Whittaker
Tel: +44 (0)1743 454992
Email: paul@inovar-communications.com

Managing Director
Nick Williams
Tel: +44 (0)1743 454991
Email: nick@inovar-communications.com

Consulting Editor
Dr David Whittaker
Consultant, Wolverhampton, UK

Submitting news and articles
We welcome contributions from both industry and academia and are always interested to hear about company news, innovative applications for PM, technology developments, research and more.

Please contact Paul Whittaker, Editor
Tel: +44 (0)1743 454992
Email: paul@inovar-communications.com

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Tel: +44 (0) 207 1939 749
Fax: +44 (0) 1743 469 909
Email: jon@inovar-communications.com

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POWDER METALLURGY REVIEW

A focus on quality control

A reliable, cost effective and in-line method to detect defects in Powder Metallurgy parts in the green state is regarded by many in the industry as the 'holy grail' of PM quality control. This ambition may be nearing reality thanks to the work of the EU funded DIRA-GREEN project. With the increased levels of component quality such a system would offer, the benefits for the PM industry are clear. We report on the current state of this project (page 51).

A company that has recognised the benefits of pushing the boundaries of quality control is Turkish PM parts maker Tozmetal. The company, which specialises in automotive components and exports up to 90% of its production, is an active participant in the DIRA-GREEN project. We report on a recent visit to the company (page 31).

Following the theme of quality in PM parts production, metallography has many advantages as a method to characterise sintered products, helping to maintain quality and understand issues that arise. In part two of our Introduction to Metallography, Thomas F Murphy, Hoeganaes Corporation, shares the best techniques to reveal and examine the microstructure of PM samples (page 39).

Those with an interest in metal Additive Manufacturing may be interested to learn that in April this year we will be launching a new magazine focused on this exciting sector. Available in both print and digital formats, *Metal Additive Manufacturing* will bring together news and articles on technical and commercial developments in the industry. Visit www.metal-am.com/magazine for more information.

Paul Whittaker
Editor, *Powder Metallurgy Review*

Cover image
Micrograph of carbon-free, powder forged, low-alloy steel processed with a two-step etch/stain. Illumination using polarised light with a sensitive tint filter (courtesy Hoeganaes Corp.)

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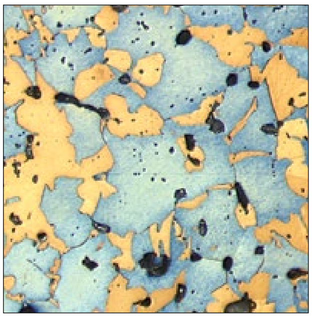

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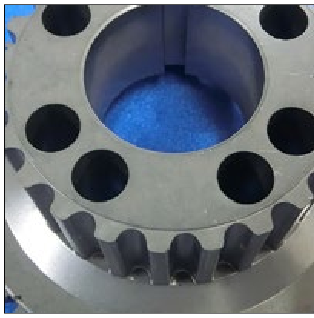

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To submit news for inclusion in *Powder Metallurgy Review* contact Paul Whittaker paul@inovar-communications.com

Netshape Technologies acquires leading competitor Capstan Tennessee

NetShape Technologies, Inc., based in Floyds Knobs, Indiana, USA, has announced the acquisition of Capstan Tennessee Inc., a leading Powder Metallurgy (PM) competitor serving the precision components market. The terms of the transaction have not been disclosed.

Following the announcement the Capstan Tennessee facility will be known as NetShape Rockwood. "We are very excited to add the Rockwood facility to the NetShape team. This acquisition adds significant technology and capabilities to NetShape, further expanding our addressable applications in the market and supporting our goal of being the leader in innovative customer solutions," stated Dax Whitehouse, Chief Executive Officer of NetShape.

Capstan Tennessee's former General Manager, Loren Bone, has assumed the role of Director of Operations for NetShape Rockwood. "I am looking forward to becoming a part of NetShape and to be able to expand our sales, marketing and engineering capabilities to better serve our customers," stated Bone.

"The plant in Rockwood, which is ISO 9001 registered, has an outstanding reputation in the market and brings significant added technology to NetShape, further helping us to serve your needs more fully. This acquisition is additive to our capabilities and capacity, and we do not anticipate product shifts between plants," stated Don Leonard, Chief Marketing Officer .

www.netshapetech.com

Concentric AB completes acquisition of GKN Sinter Metals de Argentina SA

Concentric AB, a leading manufacturer of pumps for diesel engines and hydraulic systems, has announced the acquisition of GKN Sinter Metals de Argentina SA, a supplier of engine pumps in South America.

The move is intended to strengthen Concentric's presence in the region. GKN Sinter Metals' production facility in Chivilcoy, Argentina, will provide Concentric with an important foothold in the Mercosur trade union, thereby enabling further penetration of the South American market.

The acquisition gives Concentric direct access to the commercial vehicle market in South America and will enable Concentric to build even closer relationships with its existing global customers. There are also operational synergies as Concentric will be able to in-source a share of its global purchases of sintered components.

The plant will initially continue to focus on the manufacture of engine products but, in the long-term, Concentric would also like to introduce the manufacture of hydraulic products to this facility. For the year ended 31st December 2014, GKN Sinter Metals de Argentina made sales of approximately US $12 million with 166 employees.

The transaction was completed on 30 January, 2015, and has gained all the necessary approvals. The current managing director at GKN Sinter Metals de Argentina will remain with the company and help integrate the business over the coming year.

www.concentricab.com

SHW AG set for major capacity expansion

Germany's SHW AG, a leading supplier of automotive pumps, engine components and brake discs, has announced it will raise approximately €24.6 million from the issue of new shares and plans to invest in capacity expansion.

The company's CEO, Dr Thomas Buchholz, stated, "We will use the proceeds from this capital increase primarily for an expansion in our capacity to accommodate a recently won series production contract from a leading US OEM for a global engine platform and for accelerating our international growth."

The pumps will be produced in North America, China and Europe and will, it was stated, secure the group's international growth far into the next decade. In addition, SHW AG is currently in discussions for further joint ventures for the Brake Discs business segment, among others, and is currently assessing its options to expand the production of the Pumps and Engine Components business segment in Europe.

The issue of new shares has been carried out in the context of a capital increase from authorised capital. The execution of the capital increase was expected to be entered into the commercial register on 19 February 2015. The capital increase results in a rise in the company's share capital from €5,851,100.00 to €6,436,209.00. The subscription rights of shareholders have been excluded. The new shares will carry full dividend rights as of 1 January 2014.

Currently, the SHW Group has four production sites in Germany located in Bad Schussenried, Aalen-Wasseralfingen, Tuttlingen-Ludwigstal and Neuhausen ob Eck, and one site in Sao Paulo, Brazil. With just over 1,150 employees, the company generated group sales in fiscal year 2014 of €430 million.

www.shw.de

Sumitomo Electric Industries reports Powder Metallurgy sales of $121 million in Q3

Sumitomo Electric Industries Ltd (SEI), based in Itami, Japan, reported a strong fiscal 2014 3rd quarter which saw sales up 12.6% to Yen 732.2 billion ($6.108 billion) compared with the same quarter in 2013. Overall sales for the 9 months to December 31, 2014, were up 9.7% to Yen 2,042 billion ($17.047 billion).

The company's 'Industrial Materials & Others' division saw 3rd quarter sales increase by 3.5% to Yen 79.3 billion ($661.9 million) taking sales for the 9 months to Yen 236.2 billion ($1.971 billion). This division is the third largest after the 'Automotive' and 'Environment and Energy' divisions, and includes the production of cemented carbides (hardmetals), Powder Metallurgy (PM) parts, plus W, Mo, heavy metal, thermal management materials, ceramics, diamond tools and hardmetals produced at the fully owned A.L.M.T. subsidiary.

Sales of PM products in the 3rd quarter rose by 12.4% to Yen 14.5 billion ($121.0 million) and in the 9 months to December 31 to Yen 42.9 billion ($358.1 million). Hardmetals (cemented carbides) sales increased by 8.5 to % to Yen 22.9 billion ($191.2 million) in the 3rd quarter, and for the first 9 months totalled Yen 66.8 billion ($557.6 million).

Sales at A.L.M.T. rose by just 0.9% to Yen 11.2 billion in the 3rd quarter. Overall sales for A.L.M.T. in the first 9 months were Yen 36 billion ($300.5 million), a 15% increase compared to the same period in 2013.

www.global.sei.com

Hilti enjoys growth in all market regions

Hilti Group has reported a successful 2014 with figures showing a 7.5% rise in sales over the previous year (in local currencies). When expressed in Swiss Francs, sales for the group increased 3.6% in the period, resulting in total sales of CHF 4,497 million (US$ 5.2 billion) in 2014.

Overall, the economic environment developed favourably for the Hilti Group in 2014, albeit with substantial regional differences, stated the company. Growth of the construction sector was positive in Northern and Central Europe, the Middle East, North America and in some Asian countries while markets in Southern Europe and parts of Eastern Europe and Latin America were facing difficulties. In addition, the group continued to be subject to negative exchange rate impacts, in particular in Russia, Eastern Europe, Latin America and Japan.

Against this backdrop, the Hilti Group stood its ground well and posted growth in all market regions. Expressed in local currencies, growth was most pronounced in emerging markets with 14.6% in Latin America, 14.9% in Eastern Europe / Middle East / Africa and 10.6% in Asia/ Pacific. Despite a severe winter, sales in Northern America grew by 9.5%. After a slightly negative result in 2013, Europe has returned to growth (+3.5%).

"Having increased our investments in sales and products, we managed to accelerate our growth as planned. Thanks to this, we are well on track in year one of the implementation of our revised Champion 2020 Corporate Strategy," CEO Christoph Loos stated when commenting on the Group's sales growth. "However, after last week's currency turbulences we expect 2015 to be significantly more challenging for us."

www.hilti.com

GKN Powder Metallurgy reports growth in North America, China and Europe

GKN plc has reported its results for the year ended 31 December 2014, showing organic sales for the group increased by £303 million (4%) to £7,456 million. Organic trading profit increased £66 million to £687 million (11%) over the previous year.

The GKN Powder Metallurgy division, which comprises GKN Sinter Metals and Hoeganaes, recorded organic sales for 2014 of £916 million. Good growth was achieved in North America, China and Europe but sales in South America fell due to weaker automotive and industrial markets, the company stated.

The organic increase in profit was £13 million, including the absence of £5 million of restructuring charges reported in 2013. The impact of currency translation was £6 million adverse (7%). The divisional trading margin was 11.0% (2013: 10.1%, or 10.6% excl. restructuring charges).

Reflecting its move into more advanced applications of powder metal technologies, GKN Powder Metallurgy stated that it is expanding its facilities in North America with more complex and efficient tooling and presses. It has signalled its commitment to the Chinese market with the expansion of its two production facilities there and also announced a technology collaboration agreement with McPhy Energy to develop solid state hydrogen storage solutions.

During the year, Hoeganaes made progress in the development and commercialisation of high technology powders for Additive Manufacturing. For example, highly alloyed tool steels, nickel based alloys and specialised stainless steel powders have been developed and the first commercial shipments made. Early development work also progressed on titanium powders for Additive Manufacturing.

New President of Engineering GKN Automotive

GKN also announced that Peter Moelgg has been appointed to the position of President of Engineering GKN Automotive, covering the GKN Driveline and GKN Powder Metallurgy divisions.

Moelgg will head engineering across the two divisions. He joined GKN in 1979 and has held a number of senior engineering and general management positions in GKN Driveline and GKN Powder Metallurgy, most recently as President Europe and Asia Pacific for GKN Sinter Metals.

"I am extremely excited by this new role; GKN has a wealth of engineering expertise and experience to draw on from across the Driveline and Powder Metallurgy divisions," stated Moelgg.

www.gkn.com

Avure opens isostatic pressing application centre in Sweden

Sweden's Avure Technologies, a leading manufacturer of ultra-high pressure systems, has established a state-of-the-art application centre to assist fabricators utilising advanced materials in the development of hot and cold isostatic pressing (HIP, CIP) applications. The new facility, adjacent to Avure's manufacturing plant, is equipped with two HIP presses and one CIP press. HIP technology produces parts with excellent isotropic material properties, offering the highest possible density of all available compaction methods.

"The Application Centre allows us to collaborate further with component fabricators in areas such as Additive Manufacturing, Metal Injection Moulding and Investment Casting to ensure they select the best pressing systems to match their needs," stated Jan Söderström, CEO of Avure Technologies AB. "We can help them verify their fabrication processes and determine parameters for cycle optimisation before they go into full-scale production."

Currently hosting projects related to densification (defect healing) and the removal of residual porosity in Investment Castings, the Application Centre provides the opportunity to evaluate the latest in HIP technology, such as quenching under full pressure.

"Traditionally, HIP has been used for densification, but the trend is now to combine densification with solution treatment, quenching, ageing and/or other heat treatment processes in the same cycle," explained Avure's Peter Henning, Business Unit Director-AMD. "This leads to significant savings in lead-time, improved product quality and lower costs and energy savings resulting from fewer transports and re-heating."

The application centre CIP has a working pressure up to 1,200 MPa, while the HIPs have a working range up to 207 MPa and 2000°C. These presses are equipped with either Uniform Rapid Cooling (URC) or Avure's proprietary Uniform Rapid Quenching (URQ) capability, which permits cooling rates of >3000°C per minute to be achieved.

"Having a well-equipped centre for testing has proven to be a very powerful tool in discussions with prospective adopters of HIP technology," added Henning. "Additionally, we offer services to evaluate the chemical composition, porosity and mechanical properties of materials after testing."

Avure's isostatic pressing application centre in Västerås, Sweden

With vigorous development of new manufacturing techniques in the HIP arena, such as near-net shape for Powder Metallurgy, MIM, and especially Additive Manufacturing, Henning expects Avure's application centre to become an integral part of component fabricators' process optimisation and testing. "It will be an important, cost-effective step before parts manufacturers invest in new equipment or enter full-scale production," he stated.

When not engaged in customer testing, the centre's capacity is used for university or research institute projects exploring new HIP applications.

www.industry.avure.com

UC Rusal begins $52 million upgrade to its aluminium powder plants

Russia's UC Rusal, a leading global aluminium producer, has announced the start of its metal powder business modernisation programme with a total investment set to reach US$52 million. The programme will see the upgrading of its Powder Metallurgy plants in Volgograd and Shelehov and aims to increase production of aluminium powder from 20,000 to 25,500 tonnes per year.

Rusal hopes to expand its market share in the Russia and CIS markets from 54% to 76%. The company stated that as part of the programme it is investing in the development of modern dry and wet grinding technology that will allow it to penetrate the aluminium paste segment. Alongside this, the company will also invest in the development of new technology to reduce powder production costs, to produce new types of gas developing agents used in the manufacture of aerated concretes and high-tech pigments for coatings.

"Our powder business has good prospects and the announced long-term investment programme will enhance its efficiency. Modernisation and new equipment will allow Rusal to increase its market share in powders and to take advantage of the potential that the market offers," stated Alexey Arnautov, UC Rusal's Deputy Director for New Projects.

UC Rusal has also announced that it has completed a transaction with JSC 'Fund for support of investment projects in the Republic of Komi' to obtain the remaining 20% stake in OJSC Boksit Timana (Timan). Following the completion of this transaction, Rusal now owns 100% of the mine.

The transaction was carried out as part of Rusal's asset consolidation programme, which is aimed at securing safe supplies of raw materials to the company's aluminium plants.

"Currently, RUSAL is implementing a strategy to become self-sufficient in raw materials. Timan is a strategically important Rusal asset in Russia, that makes 30% of the country's bauxite deposits. Moreover, Timan bauxite is of high quality and can be mined at low cost in an open pit. This deal has been accomplished following several years of negotiation and addresses the requirements of both parties," stated Yakov Itskov, the head of Rusal's Alumina division.

OJSC Boksit Timana is located in the Republic of Komi, Russia. The mine has a rich Vorykvin deposit of bauxites, estimated at 260 million tonnes, with annual bauxite production capacity estimated at around 3 million tonnes per year. The bauxite is used for alumina production at the Urals and Bogoslovsk refineries. Timan employs more than 500 people.

www.rusal.ru

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Kennametal looks to move Latrobe tungsten powder operations to Huntsville, Alabama

Kennametal Inc is planning to move the tungsten carbide powder production operations from its Kingston facility in Latrobe, Pennsylvania, USA, to a state-of-the-art facility in Huntsville, Alabama. The proposed move is part of an integration of recent acquisitions which included the purchase of the Huntsville site and tungsten materials business from Allegheny Technologies Inc in 2013.

"Kennametal is continually looking at opportunities within its global manufacturing operations to maximise resources, identify synergies and increase efficiencies to better serve customers," Christina Sutter, Kennametal's Corporate Communication Manager told *Powder Metallurgy Review*.

The move is expected to complete later this year. "We are currently in negotiations with the United Autoworkers union over the move and effects of closing," added Sutter.

www.kennametal.com

China sees high growth in copper powder production

China has in the past decade seen annual growth rates of around 25% for the production and consumption of copper and copper base powders. According to an article by Jingguo Zhang, et al (Beijing General Research Institute for Nonferrous Metals and GRIPM Advanced Materials) published in Powder Metallurgy (Vol 57, No 5 December 2014), China produced around 45,000 tonnes of copper and Cu-base powders in 2012 which represents 40% of the world's total. Europe is said to have 25% of global market share, North America 20% and the rest 15%.

Main application areas for Cu powders include diamond tools, friction materials, carbon brushes, self-lubricating bearings, structural powder metallurgy components, and Metal Injection Moulded (MIM) parts.

In terms of tonnage consumption of Cu and Cu-based powders for the individual areas in China, diamond tools used around 9,000 tonnes in 2012, followed by friction materials at 5,000 tonnes, carbon brushes (mainly electrolytic grades) 4,000 tonnes, and Cu powder used in MIM at around 4,500 tonnes. The main MIM application is for heat sinks (or heat pipes) produced at a number of plants in China and also Taiwan.

Production routes for copper powders in China include electrolysis (ten producers), water and gas atomisation (>50 producers), hydrometallurgy, and crushing/grinding.

www.gripm.com

AMG to sell 40% stake in graphite businesses

AMG Advanced Metallurgical Group N.V. (AMG) has agreed to sell a 40% equity interest in AMG Graphit Kropfmühl GmbH and a 10.33% equity interest in Bogala Graphite Lanka PLC to Alterna Capital Partners for a combined cash price of $38m. The transaction is expected to close during the first quarter of 2015 and is reported to be in line with AMG's strategy to expand its critical materials business while at the same time continuing to reduce net debt.

"We are excited to partner with AMG and their management team to progress AMG Graphite's growth strategy. We believe AMG Graphite has demonstrated a strong track record of providing customers with high quality products and services and the Company is well positioned for continued growth," stated Roger Miller, Managing Partner of Alterna.

AMG Graphite is one of the world's leading graphite producing and refining companies, with mining activities in Germany, Africa and Asia. With an 80% shareholding, AMG Graphite will remain the majority shareholder in Bogala Graphite Lanka PLC.

www.amg-nv.com

MIT develops new powder tungsten-chromium-iron heavy alloy

Researchers at the Department of Materials Science and Engineering, Massachusetts Institute of Technology (MIT), Cambridge, USA, have reported the development of a new tungsten-chromium-iron Powder Metallurgy alloy that could replace depleted uranium and existing tungsten heavy metal alloys in armour-piercing projectiles.

The W-7Cr-9Fe alloy is reported to be significantly stronger than commercial tungsten heavy alloys showing a nanoindentation hardness of 21 GPa, which is about double the nanoindentation hardness of nanocrystalline iron-based alloys or coarse-grained tungsten.

The material is made by high-energy ball milling of the W-Cr-Fe powder mixture. This creates repeated shearing of the metal powders, with the shearing driving the alloying elements to intermix while competing thermally activated recovery processes allow the alloy to return to its equilibrium state.

Zachary C Cordero reported the researchers' results in a paper at the MIT Materials Day held in October, 2014, and in a paper published in the journal Metallurgical and Materials Transactions (Vol 45 No 8, 2014, 3609-3618). The paper proposed a simple model to predict chemistries in a given alloy that will form a solid solution and validated it with experiments.

The improvement was achieved by compacting metal powders in a field-assisted sintering hot press, with the best result, measured by the fine grain structure and highest hardness, achieved at a processing time of one minute at 1200°C. Longer processing times and higher temperatures led to coarser grains and weaker mechanical performance.

Cordero was able to achieve ultrafine grain structure of about 130 nanometers in the W-7Cr-9Fe compact, confirmed by electron micrographs.

A compacted metal alloy pellet sits next to as-milled tungsten chromium iron metal powders. The steel balls are used to deform the metals in a high-energy ball mill (Courtesy Denis Paiste, MIT)

"Using this powder processing route, we can make big samples up to two centimetres in diameter, or we could go bigger, with dynamic compressive strengths of 4 GPa. The fact that we can make these materials using a scalable process is maybe even more impressive," stated Cordero.

web.mit.edu

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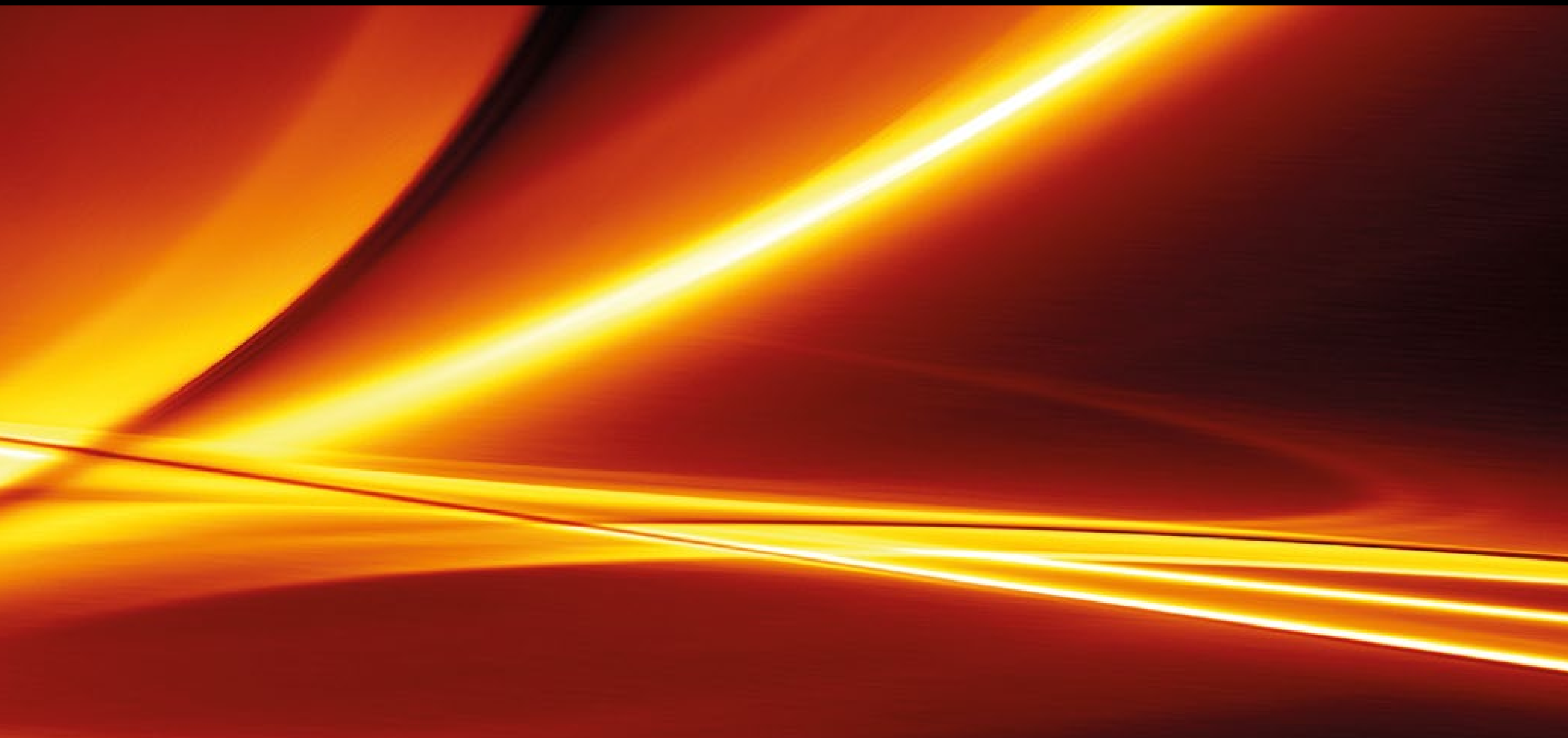

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Hitachi Chemical to establish regional headquarters in California

Japan's Hitachi Chemical has reported that it will establish a regional headquarters in the USA, based in Cupertino, California. Effective from April 1, 2015, Hitachi Chemical America Ltd (HCA) will be responsible for inter-regional sales and marketing management functions, identifying new business opportunities and regional compliance issues relating to subsidiaries in the USA.

Hitachi Chemical currently has one sales subsidiary, two manufacturing subsidiaries and one research subsidiary in the USA. Hitachi Powdered Metals (USA) Inc. will become a wholly owned subsidiary of HCA.

Hitachi Chemical also reported third quarter results for fiscal 2014 which saw sales rise by 6.4% to Yen 393.7 billion ($3.289 billion) with operating income increasing by 18.6% to Yen 25.8 billion ($216.3 million).

The 'Advanced Components & Systems' division which includes sintered friction materials and structural PM parts production, reported a 6.4% increase in sales to Yen 183.3 billion ($1.531 billion).

www.hitachi-chem.co.jp

Harper International opens new HQ and updates research centre

Furnace and thermal processing specialist Harper International has announced the opening of new corporate headquarters and improvements to its Technology Research Centre in Buffalo, New York, USA.

The building includes new office space for engineering, technology, operations, sales and support staff and an improved Technology Research Centre. "Creating synergy with our brand, mission and vision, the new headquarters provides us with the environment necessary to deliver the most innovative thermal processing systems possible," the company stated.

The new centre provides a wider variety of on-site thermal systems for customers to gather data and fine tune their processes. Clients can use the facility for process development and process optimisation as they work towards commercial scale-up.

"No other partner can offer the same capabilities in both batch or continuous furnaces, sizes from small kilns to large furnaces and furnace conditions from atmospheric to nitrogen or specialty gases, with temperatures up to 2500°C."

www.harperintl.com

Hilti moves into new innovation centre

Hilti Corporation has opened a new innovation centre at its corporate headquarters in Schaan, Liechtenstein. With a total investment of some CHF 100 million (US $98m), the Innovation Centre is the largest investment project in Hilti's history.

"Differentiation of products and services will be a decisive competitive factor for sustainable business success. In our drive to further enhance our leading position, we must strengthen our innovative capacity. This is where the new Innovation Centre will play a key role," stated Dr Stefan Nöken, member of the Executive Board and in charge of the construction project.

The facility will house some 400 workplaces in offices, testing premises, laboratories and workshops. "The physical proximity and the optimised process flow will result in more effective and efficient research and development work. Thanks to a flexible design of infrastructure, multiple work processes can be integrated in a creative environment that will allow our employees to develop innovative solutions with superior added value for our customers," added Dr Nöken.

Following the completion of the innovation centre, Hilti announced further investment at the Schaan site with refurbishment planned for the main building.

www.hilti.com

European Powder Metallurgy Association launches Vision 2025 Roadmap

The European Powder Metallurgy Association (EPMA) has announced the publication of its revised Vision 2025 Powder Metallurgy Roadmap. Vision 2025 has been produced by the association and its members as a tool to aid in the promotion of the PM industry to government, third parties and end users.

"The EPMA owes a big thank you to the members of the Steering Committee, which consisted of a number of well-known industry figures, who have worked on the EPMA's behalf to collate information from across the EPMA Members spectrum to turn this extensive project into a reality," stated Jonathan Wroe, EPMA's Executive Director.

"The Vision 2025 brochure covers many aspects, which will be very useful to third parties, such as government and funding agencies, as the content provides market overviews for the five key sectors that currently help to make up the entire PM industry, Additive Manufacturing, Hardmetals and Diamond Tools, Hot Isostatic Pressing, Metal Injection Moulding and Structural PM Components."

www.epma.com

POWDERMET2015 conference programme now available

The conference programme for the POWDERMET2015 International Conference on Powder Metallurgy & Particulate Materials has now been published. The event, which takes place in San Diego, California, USA, from May 17–20, 2015, is organised by the Metal Powder Industries Federation (MPIF). In addition to an extensive conference programme, the event also features a major PM trade exhibition.

POWDERMET2015 is being held in conjunction with the Additive Manufacturing with Powder Metallurgy (AMPM2015) Conference. All of the technical sessions, special events and global exhibition will be shared and open to all POWDERMET2015 delegates.

The event's general opening session will feature a keynote presentation entitled, "The New Industrial Revolution" by Chris Anderson, Co-founder and CEO, 3D Robotics and former Editor-in-Chief of Wired magazine.

www.mpif.org

GKN Danyang receives award from China's largest synchroniser systems supplier

GKN Sinter Metals Danyang has received an Excellent Supplier Award 2014 from Tianjin Tanhas Technology Co., Ltd, China's largest supplier of synchroniser systems. The award was formally presented at the company's Annual Supplier Conference 2015 in Tianjin.

Tianjin Tanhas Technology Co., Ltd has an annual production of more than 15 million synchroniser systems. GKN Danyang has worked with Tanhas since 2008 and delivered 540,000 synchroniser hubs to Tanhas in 2014.

GKN Danyang has received the award from Tanhas for the second year in a row. In 2014 Tanhas acknowledged the outstanding quality and on-time delivery of GKN Danyang with its Excellent Quality Supplier Award.

Jansen Wang, Sales Director of GKN Sinter Metals China, received the award on behalf of the Danyang facility. "GKN Powder Metallurgy can bring value to customers in many ways. We can help customers to win market share thanks to our optimised solutions and we can also enhance the efficiency of their product manufacturing processes," stated Wang. "Above all, we are delighted that our excellent quality and delivery has once again been recognised by this award."

www.gknsintermetals.com

High visitor numbers expected at China's leading PM exhibition

The annual PM China event has steadily grown in recent years and 2015's event promises to be the largest and most successful in the series to date. The 2015 China (Shanghai) International Powder Metallurgy Exhibition and Conference takes place from April 27-29 in Shanghai, China.

The event, which attracts key international industry suppliers as well as a huge number of specialist Chinese companies, has been boosted by the ongoing and rapid growth in both conventional Powder Metallurgy and Metal Injection Moulding in China.

In addition to the large trade exhibition, a parallel symposium will see presentations from a number of international materials and technology suppliers.

PM China's Maggie Song told PIM International, "Market demand for PM and MIM remains strong in China and the demand for upgrading technology is even stronger. We invite the international community to join us at PM China to find out what you can do to meet growing market demand, as well as the right solutions and partners."

For more information email Maggie Song at pmexpochina@163.com or visit the event website.

www.cn-pmexpo.com

North American distributor named for Chinese nickel powder producer

Canadian New Energy/Electronic Materials Corporation (Cnem), based in Mississauga, Ontario, Canada, has been appointed North American distributor for Jinchuan Group, China's largest nickel producer. Cnem is responsible for sales of the group's carbonyl nickel powders.

The company stated, "Seizing upon the withdrawal of Norilsk and its 8 million lbs. capacity from the market, Jinchuan recently commissioned a new carbonyl facility. The plant's annual output is expected to exceed 10 million lbs. and provide the ability to expand nickel powder sales beyond the Chinese domestic market." Markets for Cnem's powder include MIM, PM, batteries and fuel cell electrodes.

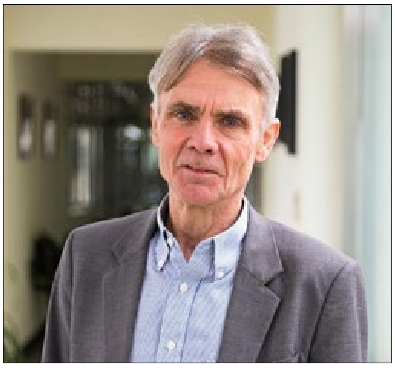
www.cnemcorp.com

Höganäs' Ulf Engström receives Swedish research foundation prize

Ulf Engström, a research engineer at Höganäs, has been awarded the Kami Research Foundation's prize for 2015. The award, amounting to SEK 1 million, was presented for his work on developing the iron powder process and his efforts to spread the knowledge globally.

"Powder Metallurgy was a fairly limited area when I started and it has been an exciting journey," stated Ulf Engström. "This is an honour for me and for Höganäs. We have initiated and driven most of the development in the field and, of course, not only one man has done the job."

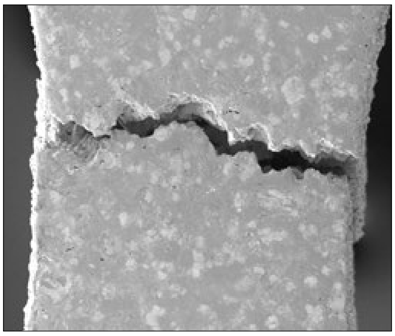
The Kami Research Foundation's prize is awarded annually and is a reward for a scientific researcher who has laid the foundation for a commercially successful technological development within the Swedish steel and metal industry. The purpose is to honour individuals who have made significant contributions to further the industry.



"The fact that Ulf Engström wins the Kami prize is not only a well-deserved personal accomplishment; it is also a success for Höganäs," added Melker Jernberg, President and CEO of Höganäs. "We strive to be an innovative company and this award shows that we have employees and ways of working that encourage and drive innovation."

www.hoganas.com

Researchers reveal fracture behaviour of sintered steel



Researchers from Spain's Universidad Carlos III de Madrid (UC3M) have identified new techniques to better understand the behaviour of sintered steels on fracturing. Scientists from the UC3M Powder Technology Group (GTP) have carried out research using a scanning electron microscope to obtain high-resolution images showing how these steels fracture when extreme loads are applied to them.

The materials that are the subject of the research are commercial sintered steels widely used in the automobile industry, specifically, an Fe-C steel, a steel pre-alloyed with molybdenum (Astaloy Mo grade, Höganäs AB) and the well-known Distaloy AE (Höganäs AB), which is iron alloyed by diffusion with copper, nickel and molybdenum.

The results have helped in understanding the connection between microstructure and properties, which in these materials, it is claimed, entails a technological challenge as not only the phases but also the residual porosity that composes their microstructure come into play. Professor José Manuel Torralba, in the UC3M department of Materials Science and Engineering and Deputy Director of the IMDEA Materials Institute, stressed the fundamental role of porosity in these steels. "The research has revealed, among other things, that the most angular and irregular pores are the first points of 'nucleation,' that is, those that initiate the breaking," stated Prof Torralba.

"Mechanical and in-situ characterisation tests performed in the scanning electron microscope have been essential in understanding the mechanisms of fracture," which, until this research, "we have never been able to determine, but instead only intuit," added Elena Bernardo, one of the authors of the study from the UC3M Powder Technology Group.

This study has made it possible to view changes in the microstructure of the material while it is being tested. Moreover, the methodology used is claimed to be applicable to any type of alloy and not only to test its behaviour under pressure, but also its behaviour at high temperatures.

www.uc3m.es

Federal-Mogul expands range of PM materials for more efficient heavy duty diesel engines

Downsized turbocharged heavy duty diesel engines with high levels of after treatment such as particulate filter systems and selective catalytic reduction can run hotter with temperatures at the valves and turbocharger exceeding 750°C. Peak cylinder pressures are often pushed up from around 180 bar to 230 bar and beyond. This can lead to challenges in the tribology of the materials used and also in geometric issues from increased distortion around the cylinder head in combination with valve brake systems introducing side loads onto the valve stems, or higher turbo temperatures affecting press fits through differential expansion.

To overcome these challenges, Federal-Mogul has used its well proven Powder Metallurgy (PM) technology to add the FM-G15 family to its range of advanced valve guide materials, and two new PM materials, FM-T90A and FM-T82A, for turbocharger bushings.

According to Federal Mogul, the FM-G15 family has been designed to meet the requirements of heavy-duty, highly complex engine designs used today. For example, FM-G15A is an alloy developed for high temperature wear resistance and reduced valve stem scuffing through a combination of solid lubricants within a high carbon steel matrix. The solid lubricant package, combined with vacuum oil impregnation, delays valve stem scuffing in high temperature, heavily side-loaded applications.

Meanwhile, the new turbocharger bushing is made from FM-T90A, a cobalt-based, fully dense sintered alloy designed for extreme applications up to 1050°C in corrosive or oxidizing conditions. Federal-Mogul says it is superior to ferrous alloys in harsh conditions because it offers the advantages of powder metal technology, such as complex composite microstructures, not attainable by melt and cast techniques.

The other new turbocharger bushing material designated FM-T82A is a ferrous-based, fully dense composite material with reduced nickel content to provide a cost-effective solution with high temperature properties in aggressive turbocharger bushing applications. This material comprises a microstructure of austenite, alloy carbides and friction-reducing solid lubricant particles, again for operating temperatures as high as 1050°C.

www.federal-mogul.com

Federal-Mogul produces a variety of powder metal valve train components

Metal cutting and thermal spray forming in one machine

Hermle, a German machine tool manufacturer, is integrating Additive Manufacturing capability into a five-axis machining centre in a move that it states will herald a profound change in complex metal component production.

Additive production of 3D metal components often involves an energy intensive laser to melt and fuse successive layers of powder. In contrast, Hermle's MPA (Metal Powder Application) generative manufacturing technology is a thermal spray process based on lower energy kinetic compacting, or micro-forging.

A five-axis C 40 U machining centre is the host platform for the addition of MPA. The hybrid machine, known as an MPA 40, has a powder application nozzle mounted alongside the vertical milling spindle and a heater built into the 4th / 5th axis rotary swivelling table.

A high-energy jet of superheated steam propels metal powder suspended in nitrogen through a Laval nozzle onto a substrate at three times the speed of sound. The impact creates local pressures of 10 GPa and temperatures up to 1,000°C. The result is localised super-plastic deformation, forging the powder particles together and onto the component surface. The fully dense, bonded layer is machined by metalcutting using up to five CNC axes, followed by deposition of a further layer. The process is repeated any number of times to produce the required component.

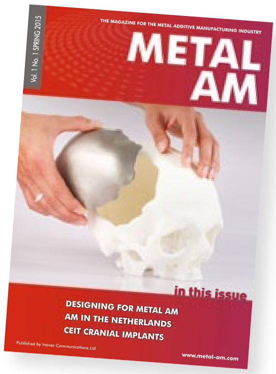
Powder grain size is between 25 and 75 microns and deposition rate for tool steel, for example, is 4 to 5 cm^3/min. Micro-forging allows dissimilar metals to be layered, with either a sharp or a smooth transition between them. Up to six materials can be made available, stored in sealed drums within the machine. Materials currently available are 1.2344 and 1.2367 hot-working steels, 1.4404 stainless steel, copper, bronze, titanium and aluminium.

A Hermle MPA 40 hybrid 5-axis machining centre with integrated Additive Manufacturing capability

Components produced can be up to 550 mm in diameter, 460 mm deep and weigh up to 600 kg. Almost any internal geometry is possible, as there is an option to use a water-soluble filler material to create internal features such as conformal cooling channels.

www.hermle.de

Metal Additive Manufacturing: A new magazine for the 3D printing of metals



Metal Additive Manufacturing, a new quarterly magazine for the metal Additive Manufacturing (AM) industry, will be launched by Inovar Communications Ltd in April 2015.

Available in both print (ISSN 2057-3014) and digital (ISSN 2055-7183) formats, *Metal Additive Manufacturing* will bring together industry news and articles on technical and commercial developments in the industry. The publication of this new magazine follows the successful launch of the www.metal-am.com website in May 2014.

"This new high quality quarterly magazine will specifically focus on developments in the Additive Manufacturing of metals. We have launched the title in response to feedback from industry professionals, who, whilst appreciating the advantages of our existing e-newsletter, also wish to have access to more in-depth information on technical and commercial advances in the AM industry in a format that they can save, either digitally or in print, for future reference," stated Nick Williams, Inovar's Managing Director.

Inovar Communications is an established publishing house with over twelve years of experience in the metal powder processing industries. Existing magazines include *PM Review* and *PIM International*.

"As with our sister publications, our aim is to not only provide relevant coverage of the industry for those currently involved in it, but to promote the benefits of metal AM to a global audience of component producers and potential end-users," stated Williams.

The launch issue of *Metal Additive Manufacturing* will be available for free download from the www.metal-am.com website in late April 2015. The printed edition will be available by subscription, as well as from Inovar Communication's stand at the Additive Manufacturing with Powder Metallurgy (AMPM) Conference, May 18-20, San Diego, USA, and the RAPID 2015 Conference and Exhibition, May 18-21, Long Beach, USA.

For editorial enquiries contact Nick Williams (nick@inovar-communications.com) or Paul Whittaker, (paul@inovar-communications.com). For advertising enquiries contact Jon Craxford, Advertising Sales Director, jon@inovar-communications.com.

www.metal-am.com

Kyoto set to host APMA2015 conference

The Japan Society of Powder and Powder Metallurgy, along with the Japan PM Association, have published a Call for Papers for APMA2015, the 3rd International Conference on PM in Asia. The event will take place in Kyoto from November 8-10, 2015.

As well as a comprehensive technical programme, a special interest programme will focus on Additive Manufacturing and Novel PM Processing. The technical programme will cover PM materials, compaction and consolidation (including CIP and HIP), sintering and post processing, powder forging, PIM, spray forming, spark plasma sintering, PM production management and PM materials. The abstract deadline is March 31, 2015.

www.apma2015.jp

Registration opens for 2015 EPMA Powder Metallurgy Summer School

The European Powder Metallurgy Association (EPMA) has announced that its 2015 Powder Metallurgy Summer School will take place in Sheffield, UK, from June 8-12, 2015. The five-day residential course will offer students and engineers new to the Powder Metallurgy (PM) industry the chance to learn about the PM process and related sectors.

The summer school will be hosted by Denzil Lawrence from the Advanced Manufacturing Research Centre and Professor Iain Todd and his team at the University of Sheffield. Topics to be covered include the manufacture of metal powders, Metal Injection Moulding (MIM), modelling, sintering, Hot Isostatic Pressing (HIP) and metal Additive Manufacturing (AM). Participants will be able to discuss and solve problems in the class room as well as gain hands-on experience of various PM processes in the University laboratories. There will also be the opportunity to visit a PM component manufacturer.

The Summer School, coordinated by Professor José Torralba, University Carlos III, Madrid, Spain, and Joan Hallward, EPMA, is designed for young graduate designers, engineers and scientists from disciplines such as materials science, design, engineering, manufacturing or metallurgy. Graduates under 35 and who have obtained their degree from a European institution are eligible to apply.

The Summer School fee of €575 covers tuition, all course materials, shared accommodation, a Welcome Reception and Summer School Dinner.

www.epma.com

Tozmetal: Turkish gear pump specialist drives innovations in PM quality control

Istanbul, the metropolis on the Bosphorus where Europe and Asia meet, is not only Turkey's largest city but also an important location for Turkey's Powder Metallurgy industry. Dr Georg Schlieper recently visited Tozmetal, a leading Turkish PM parts manufacturer, and introduces the company and its technology, as well as reviewing its activities relating to quality assurance.

Tozmetal Ticaret ve Sanayi A.Ş. was founded in 1973 in the western suburbs of Istanbul on the European side of the city. The company's name derives from the Turkish word for powder, toz. The political and economic environment was difficult at the time when the company was established, with a worldwide oil crisis and military conflict between Turkey and Greece over the island of Cyprus. Turkey had little in the way of heavy industry and there were no domestic equipment suppliers or experienced metalworkers. In short, the venture had many challenges to overcome.

It took Tozmetal around two years to source and acquire the necessary equipment to begin PM parts production. Following a period of learning how to use the new technology, production began with relatively simple sewing machine parts and bronze bearings. Turkey's sewing machine manufacturing industry was the main customer at first, however the company soon identified opportunities in the automotive sector.

Car production in Turkey began in the early 1960s with domestic and global auto makers establishing a number of plants in the country. In order to create jobs in the rapidly growing city of Istanbul, the Turkish government encouraged the growth of the auto industry and its suppliers in this region. An Opel assembly plant was built in Turkey which created a growing demand for PM components. Tozmetal turned its attention towards shock absorber parts and was selected as the supplier of these and

Fig. 1 The new Tozmetal building near Atatürk Airport (Courtesy Tozmetal)

Fig. 2 Selection of gear pump components (Courtesy Tozmetal)

Fig. 3 Rotary vane pump components produced by Tozmetal (Courtesy Tozmetal)

a number of other PM components.

Tozmetal soon became a highly knowledgeable supplier of shock absorber components. Hüsnü Özdural, General Manager of Tozmetal, joined the company in 1975 as Production Manager. Özdural recalled an amusing encounter from the early days of production. "One day," he said, "the General Manager of a major customer visited me and brought a shock absorber with him. He said there was a bird inside and every time he moved the rod of the shock absorber in and out there was a chirping sound. We tried to find the cause of the chirp and double-checked the parts we had delivered, but everything was according to the drawings. Finally we found out that our customer had copied the dimensional tolerances correctly from the original drawings of his licenser, but additional remarks in the drawings had not been translated. Neglecting these remarks had led to the malfunction of the parts and the chirp of the shock absorber. So we were cleared of blame and could continue to supply the parts on the basis of modified drawings!"

When Özdural began his career at Tozmetal there was no tool manufacturer in Turkey, so an agreement was made with a UK based company to supply tools. By 1978, stated Özdural, the financial situation had improved and investment was made in an in-house tool room. Great efforts were also made to introduce a quality management system. Özdural compiled a documented Quality Assurance Manual which was the basis for many customer audits over the following years.

Beginning in 1980 there were considerable marketing efforts oriented towards export. The first exports to Iran began in 1982 and to Germany in 1984. In 1986 General Electric Trading Co. presented Tozmetal as a potential exporter to the USA and after successfully passing quality audits the first exports to the USA began.

The 1990s were characterised by dynamic growth and the perfection of the company's quality management system. In 1992 a major enlargement of the production area and investment in modern machinery was made to increase the production capacity. Around 1996 the first oil pump parts were produced at Tozmetal. "In those days it was common to pack 100 parts together in a bag without separating them from each other. The parts could be damaged during transport, but it was accepted by our customers," stated Özdural. "Today each part is packed separately so that damage is prevented."

"You may remember that years ago new cars had to be run in very carefully and the first oil change was made after 1000 km," continued Özdural. "This was required because of metallic debris coming from the drivetrain components, which was collected by a magnet integrated in the oil drain. Today these components are so precisely manufactured that running in is no longer required."

Between 2000 and 2002 Tozmetal established contact with China, which led to knowledge transfer to a Chinese automotive company. By 2010 the original Tozmetal building had reached capacity. Over the years the city of Istanbul had expanded so much that Tozmetal was now situated in the middle of an urban district with apartments and private homes preventing further expansion at the site. The search for new premises was difficult, stated Özdural, but finally a location was found. A free trade zone had been established close to Atatürk Airport, with excellent travel connections both internationally via the airport and locally through a nearby metro station. A new building with approximately 10,000 m² of floor space was built (Fig. 1) and in 2012 Tozmetal moved in. "Visitors to Tozmetal can now fly into Istanbul in the morning and return home on the same day without getting stuck in the traffic jams of the city," added Özdural.

Today Tozmetal mainly serves the automotive industry as a tier 1 and tier 2 supplier. Annual turnover is close to €22 million and the company employs a staff of around 260 people.

Products

Tozmetal manufactures a wide range of products for a number of industry sectors, but the company's main specialisation is in automotive components. By offering high quality parts at a low cost the company has gained important customers such as Volkswagen, Skoda, Renault, Opel, Ford, Fiat, SHW, Pierburg and Stackpole. Around 85-90% of the company's production is now exported to customers in USA, Germany, France, Mexico, UK, China and others.

Over the years, valuable knowledge in a range of PM part applications has been acquired by Tozmetal. This includes a detailed understanding of gear pump technology, along with other automotive components, electronics and air conditioning compressor parts.

Gear pumps

Powder Metallurgy is the most efficient technology to produce gear pump components. Oil, fuel and other liquids are pumped by the gear pumps shown in Fig. 2. A pair of gears, an inner and outer gear, is installed in a closed housing. The eccentric inner gear is driven by a shaft. When it turns, the volume between inner and outer gear increases on one side and the liquid is sucked in. On the other side the volume decreases and the liquid is pushed out.

Gear pumps are robust and efficient. The PM parts require close dimensional tolerances on the outer diameter (0.02 mm), height (0.006 mm) and tooth profile (maximum deviation 0.04 mm).

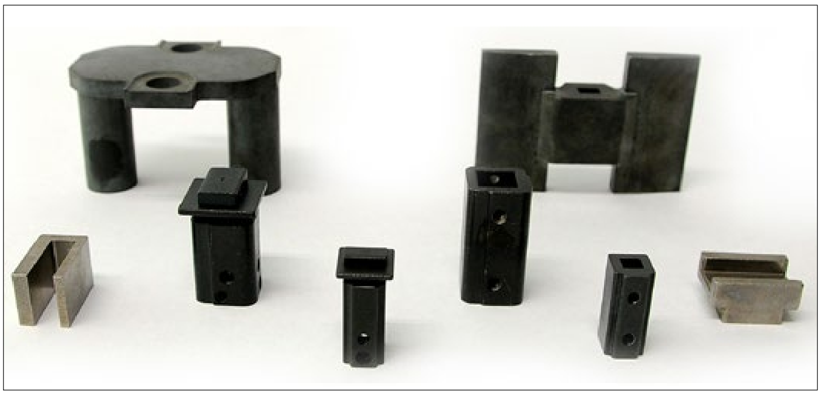


Fig. 4 Soft magnetic components (Courtesy Tozmetal)

Rotary vane pumps

Rotary vane pumps (Fig. 3) work in a similar way to the gear pump. They consist of a number of vanes extending from a slotted rotor within a housing. When the eccentric rotor rotates inside the housing a similar effect is created to that found in the gear pump. The increasing volume between the vanes on one side sucks in a liquid and on the other side the liquid is pushed out. Automotive applications of rotary vane pumps are mainly in power steering and brake boosters.

Another important product group is soft magnetic components for electromagnetic applications (Fig. 4). Compressor components for refrigerators and air conditioning, a variety of structural parts and bronze bearings, are also part of Tozmetal's product portfolio.

PM technology at Tozmetal

Tozmetal prides itself on a set of principles geared towards its current and future business. Özdural stated that, "the task for the present is to work with a team spirit and achieve the best performance, to implement the continuous improvement philosophy and understand and meet customer requirements."

"Tozmetal's vision and inspiration for the future," Özdural added, "is to obtain the highest possible quality and zero defects at the lowest cost, be innovative in management style and products and continue to be a leading market performer."

Order process

The main technical departments at Tozmetal are Engineering, Tool Design, Production and Quality.

Fig. 5 Powder store at Tozmetal (Courtesy Tozmetal)

Fig. 6 View into Tozmetal's production hall (Courtesy Tozmetal)

Fig. 7 250 and 500 ton presses at Tozmetal (Courtesy Tozmetal)

Fig. 8 Automatic CNC turning station with a robotic arm (Courtesy Tozmetal)

"When the company receives a new enquiry the first action is a feasibility study. The feasibility team may suggest modifications of the part design in order to be able to produce the parts as economically as possible by PM technology," said Özdural.

When the feasibility has been confirmed and the manufacturing route is clear, an offer is issued to the customer. "If everything goes well, the customer approves the offer and places an order. At this point the part becomes a project." All the main technical departments are then represented in the project team formed to manage the order.

"A clear process flow is important for high quality at low cost," stated Özdural.

Tooling

Tooling is designed and manufactured in-house. The tool shop is equipped with turning lathes, CNC machining centres and EDM machines. It does not only handle the manufacture of tooling for new parts, but also the repair and maintenance of tooling in production.

Metal powders

Powders are delivered as press-ready mixtures in large bags which are directly taken to the press without any further treatment (Fig. 5). Annual powder consumption is between 2000 and 2500 tons and the company's main powder supplier is Höganäs AB, Sweden.

Production equipment

All production equipment at Tozmetal is logically arranged in the production hall seen in Fig. 6. Tozmetal has around 30 powder presses ranging from 10 to 500 tons capacity (Fig. 7). Five continuous conveyor belt furnaces are operated, four for steel and one for bronze parts. Three furnaces have built-in endogas generators. The protective gas for the other furnaces comes from external sources. One sintering furnace is equipped with a sinter hardening zone where accelerated cooling is carried out by a cold gas stream. With this technology a hardness of 450 HV can be achieved without excessive distortion of the parts. A continuous steam treatment furnace is also available.

Around 20 sizing presses, up to 250 tons, are installed in a separate sizing area. Almost 80% of production undergoes secondary operations after sizing, consequently a substantial part of the floor space is occupied by fine machining equipment.

A variety of fine machining operations are installed such as double disc grinding, centreless grinding, turning lathes, etc. Many of these operations are automatic, Fig. 8 shows two CNC turning machines with a robotic arm between them feeding and removing the parts.

Deburring is carried out by vibratory finishing or tumbling and a tunnel type washing machine is available to remove sizing oil and machining liquids. Finished parts, packed ready for shipping, are shown in Fig. 9.

Fig. 9 The week's production packed and ready for shipment (Courtesy Tozmetal)

Quality assurance

Tozmetal holds all major quality and environmental management certifications including ISO TS 16949, ISO 9001 and ISO 14001. "From the start of PM parts production at Tozmetal the factory management has always been committed to providing the best possible quality to its customers. Therefore methods of quality assurance were always of great interest, in particular non-destructive test methods," stated Özdural.

From the start of a new project, quality assurance is an integral part of the production planning process. Tooling and first approvals are carefully inspected before production begins. Gear profiles are checked on a high precision coordinate measuring machine (Fig. 10) with best fit software. Metallographic inspection for cracks and cleanliness of the powder is standard.

Crack detection

Crack detection has been an important issue at Tozmetal, as in the entire PM industry, due to the known high risk of crack formation in green parts. Powder metallurgists know that die pressed green compacts are extremely delicate because the cohesion between the powder particles is merely created by adhesion, mechanical bonding and cold welding. A particularly critical step in the PM process is the ejection of the green compacts from the die. The forces acting on the compacts at this stage may create cracks that are sometimes very difficult to detect.

Magnetic Particle Inspection (MPI) is a non-destructive test and the standard method in the PM industry to detect cracks in ferrous sintered parts. The parts are magnetised and immersed in a liquid carrying ferromagnetic particles, usually iron oxide. In the magnetic field, particles build up where cracks or other irregularities in the material structure are at the surface. The particles have pigments applied that emit fluorescent light when inspected in a dark room under a UV lamp. With this method surface cracks can be detected in sintered parts. It requires, however, an experienced person to inspect the parts and the efficiency underlies the subjective judgement of the inspecting person. To-date, attempts to automate the test have not been successful. Furthermore, the test is limited to ferromagnetic materials and the parts have to be demagnetised after inspection.

Fig. 10 High precision coordinate measuring machine (Courtesy Tozmetal)

"Tozmetal uses MPI regularly, but the disadvantages of the process motivated us to look for alternatives," stated Özdural. For many years eddy current testing has been successfully applied by Tozmetal. Eddy current is a circular electric current which is created by a changing magnetic field. It only occurs in electrically conductive materials, including non-magnetic ones. Eddy current probes contain a coil powered by an AC current creating an alternating magnetic field which, when placed in the vicinity of an electrically conductive material, induces eddy currents in the surface. The depth of eddy currents depends on the AC

Fig. 11 Eddy current test stands (Courtesy Tozmetal)

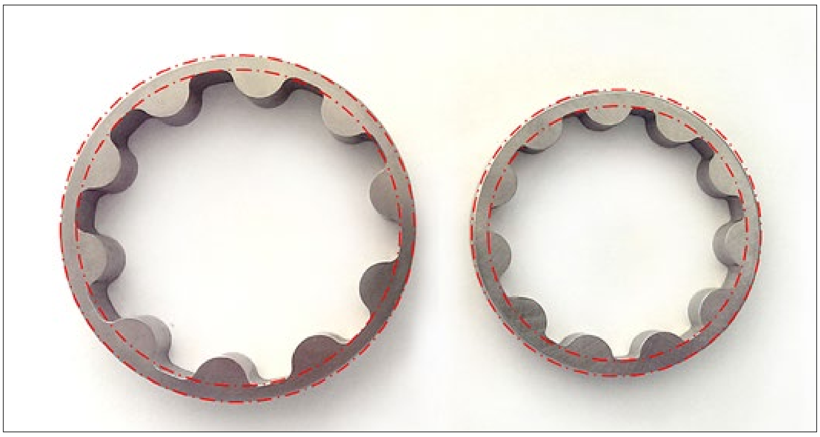


Fig. 12 Oil pump gears used for eddy current test (Courtesy Tozmetal)

frequency and the electrical conductivity of the material.

Since the eddy current itself also creates a magnetic field which interacts with the magnetic field of the coil, it affects the amplitude and phase of the coil current. Measuring the coil impedance can therefore be used to determine the eddy current. A change in the conductivity of the tested material is registered as a change of eddy current and consequently the impedance of the coil. As this test is based exclusively on electrical measurements, it is fast and can be automated easily. It is best suited to flat part surfaces. On irregularly formed surfaces it is typically unsuccessful.

Fig. 11 shows two eddy current test stands at Tozmetal which are used for testing the oil pump gears shown in Fig. 12. The thin outer rim of these parts is particularly sensitive to crack formation during ejection from the die and transport to the sintering furnace. Therefore the area indicated by the red circles is inspected by eddy current testing. Three eddy current probes are mounted in the test stand, one on top, one on the opposite side and one on the outer diameter of the test part. The parts are rotated between the probes during the test. If the eddy current signal exceeds a certain value, the respective part is categorised as defective.

R&D projects

Tozmetal has recently carried out two research projects in cooperation with local universities and participated in two research projects within the European 7th Framework Programme (FP7). Both EU projects, SINTEST and DIRA-GREEN, are related to the non-destructive testing of PM compacts. Although Turkey is not a member of the EU, Tozmetal took advantage of the country's Associated Partnership that puts it in a position to actively participate in EU funded research and even receive funding from the EU.

In particular, the DIRA-GREEN project, which ended in September 2014, puts Tozmetal in the forefront of applied research in non-destructive testing of green PM compacts. The equipment developed by the project is temporarily installed at Tozmetal with the aim of continuing to explore the benefits of this important technology. A full report of the DIRA-GREEN project can be found on page 51 of this issue of *PM Review*.

Conclusion

The first PM companies in Turkey were started in the mid 1960s and in 1995 the Turkish Powder Metallurgy Association (TPMA) was founded with 20 members. Today this has grown to a membership of 125 and the Turkish PM industry is now very well established, operating at a global level.

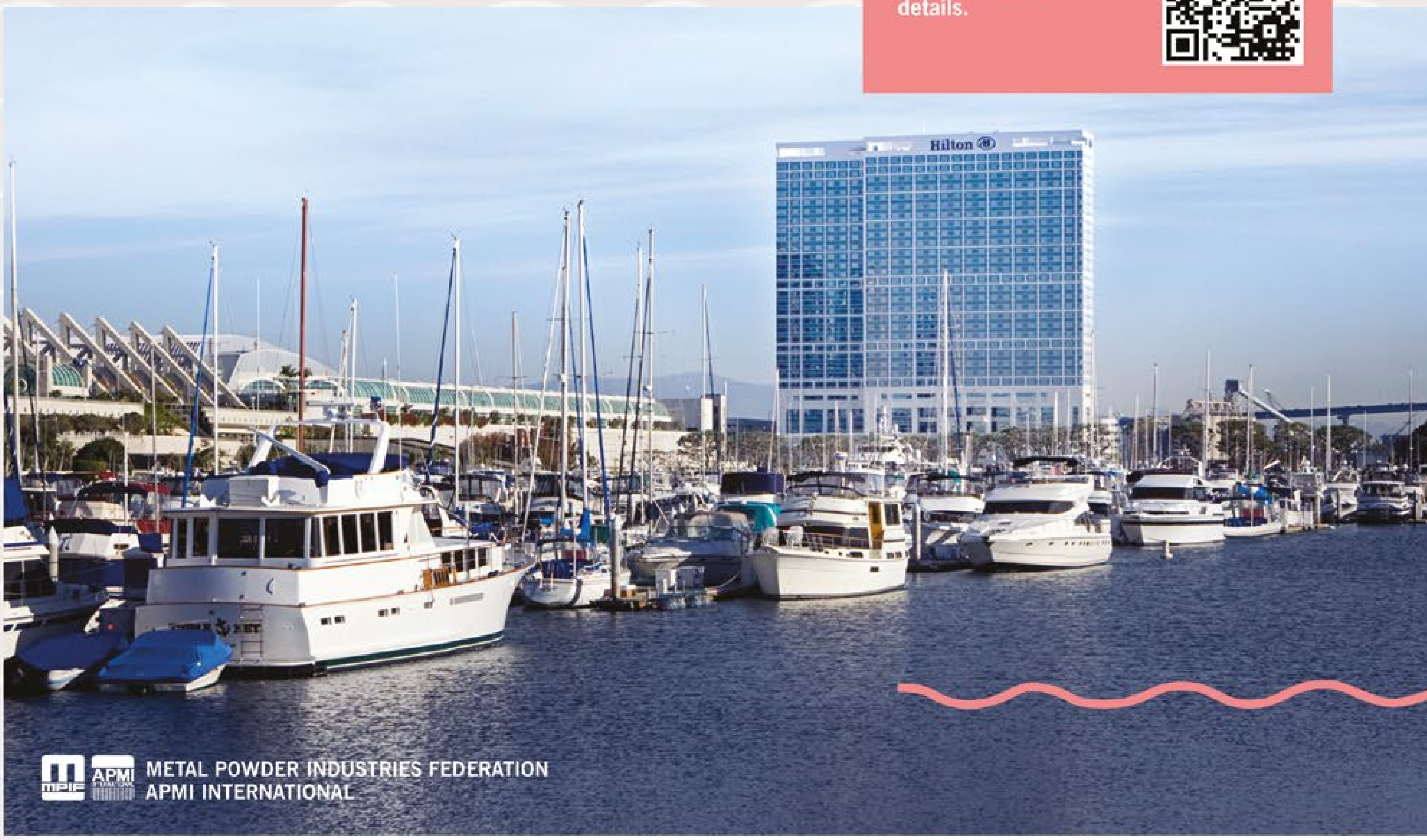
The story of Tozmetal is closely linked to the story of PM technology in Turkey as a whole. Tozmetal is an excellent example of how new technologies can be successfully implemented in a developing industrial environment, with a committed management, government support and hard-working people, for the benefit of all.

Contact

Tozmetal Tic. ve San. A.Ş.
Hüsnü Özdural, General Manager
Itanbul Atatürk Havalimanı Serbest Bölgesi, L Blok No 1, Yeşilköy, Bakırköy, Istanbul, Turkey
E-mail: ozdural@tozmetal.com
www.tozmetal.com

Author

Dr Georg Schlieper
Gammatec Engineering GmbH
Mermbacher Strasse 28
D-42477 Radevormwald, Germany
E-mail: info@gammatec.com


Hilton

Introduction to Metallography for Powder Metallurgy: Part 2, revealing and examining the microstructure

Metallography is the study of the physical structure of metals using microscopy. The process has many advantages as a method to characterise Powder Metallurgy products and helps to ensure product quality and understand issues that arise. In part two of our introduction to this important science, Thomas F Murphy, Hoeganaes Corporation, USA, identifies the best techniques to reveal and examine the microstructure of Powder Metallurgy samples.

Metallographic analysis is primarily a collection of visual and imaging techniques. Therefore, the appearance of the samples must be accurate in order to gather correct and relevant information on the part or material. The examination of Powder Metallurgy (PM) materials presents several unique challenges to this accurate representation. The most obvious is ensuring the faithful representation of the pore structure. This is absolutely necessary and can be obtained only with correct sample preparation techniques. Correct preparation will also ensure the surface is free of disturbed metal and that the true microstructure can be revealed using etching, staining or optical techniques.

The metallographic preparation and evaluation of ferrous PM parts is sometimes complicated by the presence of localised mixtures of multiple transformation products. An example can be seen in Fig. 1, where the microstructure contains several transformation products. The cooling rate was the same for each region of this field of view so the presence of various microstructural constituents is not the result of any difference in cooling rate. There are several factors that contribute to this behaviour.

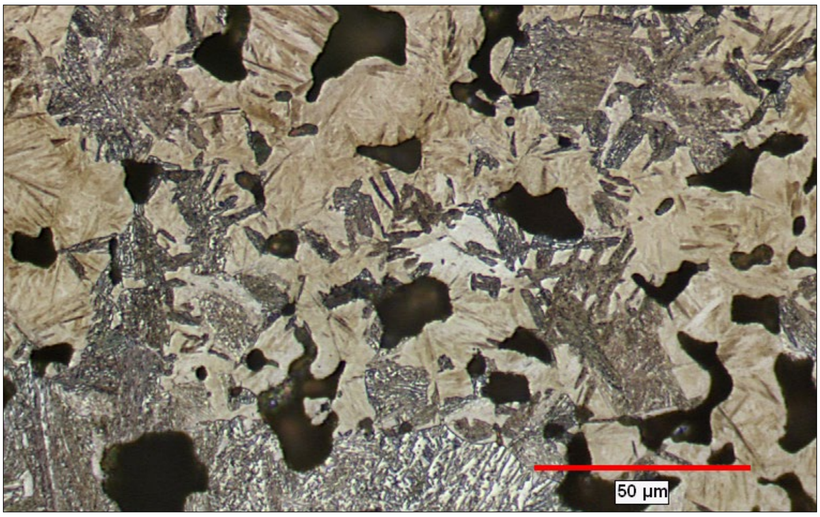


Fig. 1 Hybrid alloy using a prealloyed low-alloy steel base containing (wt.%) 0.4 Mn, 1.25 Mo, & 1.4 Ni with 1 wt.% elemental Cu + 0.7 wt.% graphite additions (FLC-4805). Sintered at 1120°C without accelerated cooling (2 vol.% nital + 4 wt.% picral)

Alloying and the PM process

Alloy composition of the powder mixture, the method used to manufacture the base powder, and the sintering conditions of temperature, time, and atmosphere all define the distribution of the alloying additives and, consequently, the local alloy hardenability. The section size, cooling rate in the sintering furnace and any secondary heat treatments determine the final microstructure. In most cases where particulate alloying additives are used in the powder mixture, the chemical composition of the material through the part volume is not homogeneous. The hardenability is variable on a local scale, where the regions containing the highest additive content have the highest hardenability.

The alloying of ferrous Powder Metallurgy alloys is accomplished using several different techniques, some unique to the PM process. This alloying involves incorporation of various amounts of elements such as copper, molybdenum, nickel, chromium, manganese, silicon and/or others into the iron-based particles, either during the manufacture of the base powder or as ingredients in the powder mixture. The choice of the additives is determined by the desired properties of the part and the tendency of the element to form oxides that are stable at the intended sintering temperature.

Chromium, manganese, and silicon form oxides that are relatively stable at the typical sintering temperature of 1120°C and are often used in the prealloyed form to minimise oxide formation. Oxides of copper, nickel, and molybdenum are more easily reduced at this temperature and are commonly used as particulate additives. It is important to remember that the additive must be diffused into austenite during sintering to be effective in enhancing most properties, especially hardenability. If the additive in the compact is in the form of an unreduced oxide or a 'free' additive, no diffusion will occur during sintering and no property improvement will be realised from those particles. In fact, the presence of these particles could diminish the performance of the compact by creating hard or soft spots, degrading the quality of sintering or increasing the nonmetallic inclusion content.

> *"It is important to remember that the additive must be diffused into austenite during sintering to be effective in enhancing most properties, especially hardenability"*

Alloying methods

Three basic methods are used to distribute alloying additives in the base-powder particles or into the powder mixture, resulting in four alloy types. The alloying methods and powder types are:

- Admixed: a physical mixture of dry particulate additives in a base powder. The additives may be particles composed of a single element, more complex combinations of multiple elements, fine ferroalloys or easily reduced oxides that are mixed into the base powder
- Diffusion - or partially-alloyed powder: elemental or oxide additive particles diffusion bonded to a base-powder surface using an annealing step

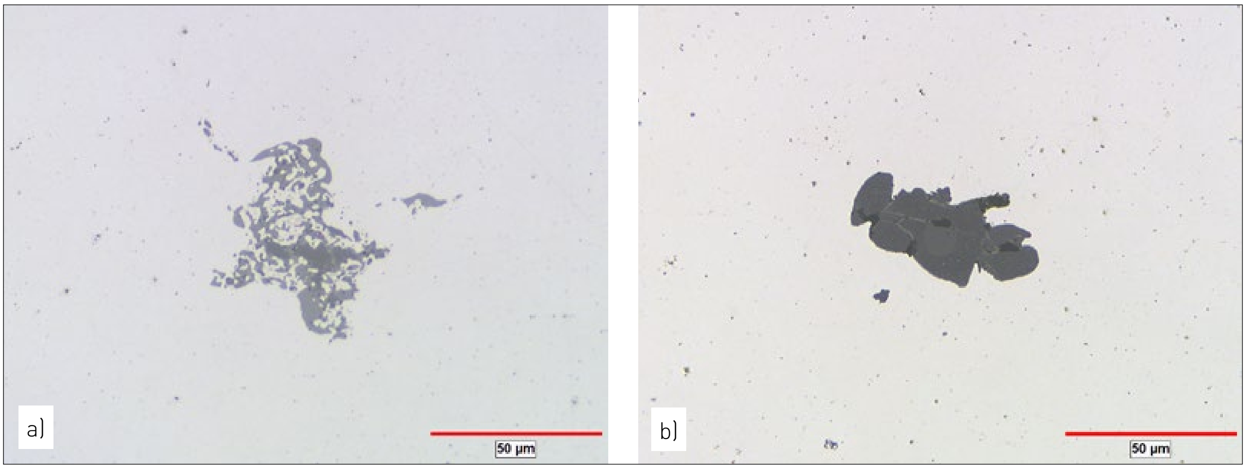


Fig. 2 Image a) shows inclusions composed primarily of MnS and characterised by a light shade of gray. Image b) shows several dark gray oxides in a multi-phase inclusion (unetched)

- Prealloyed powder: desired elements are added to a molten metal bath before atomising. Prealloyed powders are uniform in chemical composition
- Hybrid alloy: an additional alloy type is the hybrid alloy which uses diffusion-alloyed or prealloyed-base powders with further alloying accomplished using admixing techniques.

Of the four alloy types, only the prealloyed powder contains a homogeneous distribution of the alloying elements in each powder particle and, consequently, throughout a pressed and sintered part. Sintered parts made from the other three types contain micro-scale alloy gradients throughout the part volume. It is these gradients that result in local variations in the transformation products and determine the overall part properties.

Properties of PM materials

The alloying and processing of the PM parts are of crucial importance due to the fact that the properties of PM materials are determined by three controlling factors:

- Porosity/Density: volume percent, size, shape, spatial distribution and interconnectivity of the pore structure
- Composition and Alloying Method: the distribution of alloying additives is determined by the methods used to manufacture the base powder and final powder mixture, in addition to the thermal processing sequence employed to make the part
- Microstructure: the combination of transformation products is determined by the local chemical composition, the cooling rate in the sintering furnace and any secondary thermal treatments.

Clearly, local chemical composition and cooling rate have a huge impact, not only on the part behaviour in use, but also on how the sections should be prepared for metallographic analysis.

This discussion of PM alloying and processing is important from a metallographic standpoint because the individual transformation products have different physical properties and chemical activity. In looking at the physical properties, constituents and phases often vary in hardness and the softer areas may polish at a faster rate compared with the harder areas. This is especially important during final polishing where excessive polishing time, pressure or the incorrect polishing cloth could result in unwanted surface relief and an improper characterisation of the microstructure. The variation in chemical activity often results in differences in etching rates, where one region in the microstructure might appear over-etched or under-etched compared with other transformation products in the same field of view.

Sample selection, preparation and examination

Several techniques for sample selection and preparation were discussed in the first part of this two-part article [1]. As emphasised in Part 1, preparing the samples correctly is essential for performing an accurate assessment of the microstructure. The amount of reliable information available from a poorly prepared sample is minimal at best and the results from such samples could lead to incorrect conclusions. Conversely, when the sample is prepared correctly and the microstructural features are present in an unaltered condition and location, the results are correct and factual.

Two stage evaluation

Under normal circumstances, a metallographic analysis is separated into two stages; the first in the as-polished (unetched) condition and the second with the microstructure revealed using chemical or optical means. The initial as-polished examination provides information based on the interaction of the sample surface with the light from the microscope. Since the prepared samples are opaque, all information is based on how the light is reflected from the surface. Features characterised by specific colours or grey shades are visible

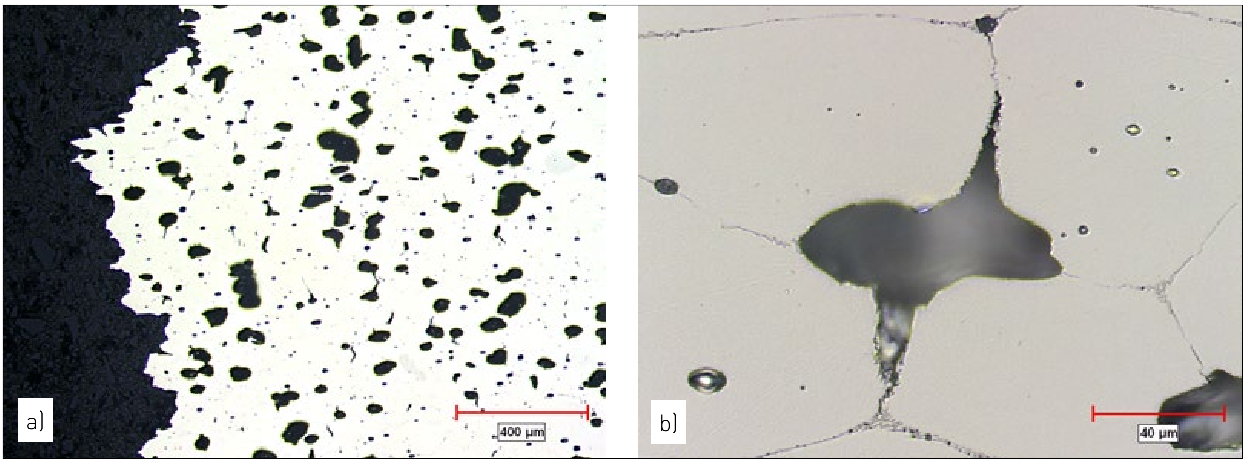


Fig. 3 Images of pores and cracks in a tensile tested part containing precipitation throughout the grain boundaries. The pores and fracture surface edge are seen in a) and a pore containing cracks perpendicular to the stress direction is seen in b) (unetched)

against the highly reflective metallic matrix due to the variation in the light absorbed and reflected by specific areas on the surface.

Distinguishing grey levels

With grey features, the difference in reflectivity must be >10% compared with the surrounding material in order to separate one area from another. Being able to distinguish multiple grey levels is important with features such as nonmetallic inclusions where several oxides or sulphides may be present in one complex feature.

The individual oxides or sulphides are often different in terms of the amount of light they reflect, i.e. their grey level. This can be seen in Figs. 2a and 2b, where images of two nonmetallic inclusions are seen. In Fig. 2a, the inclusions are light grey sulphides, while, in Fig. 2b, the inclusion is a dark grey oxide. Other important features distinguished by grey level are shown in Fig. 3. These are pores, cracks, and an exposed fracture surface cross-section where the features are composed of void space and consequently have no light reflection.

As-polished surfaces

Various microscope techniques can also be used to provide additional information while the sample is in the as-polished condition. These will be discussed in more detail later in this article. Two techniques can be used. Relief intentionally polished into the surface can be useful in showing variations in local hardness between features, where over-polishing a sample in the final preparation stages will show height differences between the hard and soft components. A second technique, polarised light, can be used to distinguish features that are cubic (isotropic) in crystal structure from non-cubic (anisotropic) features.

> *"Various microscope techniques can also be used to provide additional information while the sample is in the as-polished condition"*

As-polished surfaces are used frequently in the quantitative analysis of the nonmetallic inclusion content in powder forged specimens and to evaluate the effectiveness of the sintering process on porous samples by measuring the shape, size and distribution of the pore cross-sections. Using quantitative microscopy (stereology) to estimate the ratio of the pore surface to material volume is also an indicator of the response of the material to alloying and sintering.

The etching stage

Once the initial as-polished examination is concluded, the sample is etched and possibly stained to reveal the microstructure. At this stage, the combination of transformation products, phases, effects of diffusion, microstructural constituents, etc. are examined.

Revealing the microstructure can be accomplished using a single or two-step sequence where the freshly prepared sample is exposed to chemical solutions that affect the polished surface in highly predictable ways. The etch and/or stain procedure is used either to alter the sample surface by dissolving particular phases or affect the appearance of the surface by depositing an interference layer (stain) onto the sample surface to provide a colouration of specific features or orientation effects. Because material is removed from the prepared surface by etching and deposited by staining, it is advisable to proceed to this stage in the analysis only after the as-polished evaluation is completed.

Metallographic examination

Metallographic examination, in both the as-polished and etched conditions, should begin at a low magnification and progress to higher magnifications only after sufficient information has been gathered and documented. The low magnifications provide a better overall view of the microstructure, where larger features and characteristics are more apparent. As the magnification is increased, more localised detail can be seen. Both the unetched and etched analyses are needed to provide a complete picture of the microstructure. This is illustrated in Figs. 4 and 5 with both low and higher magnification images in each figure.

Fig. 4 shows an example in the unetched condition with a Cu-infiltrated sample containing excessive porosity and oxidation along the bottom corner. The low magnification image, Fig. 4a, shows the overall cross-section with the defect located in the lower corner of the image. Details of the porosity and oxidation in the porosity are seen in Fig. 4b. In addition to highlighting the benefits of using multiple magnifications, Fig. 4 illustrates how features may be distinguished by their characteristic colours and shades of grey before the sample is etched. In these images, the infiltrated Cu in the pore structure is the characteristic orange colour. The dark grey oxides are located in the pore structure, but the oxides are lighter in colour compared with the open porosity.

In Fig. 5, gear teeth are observed after heavy carburisation resulting from an atmosphere problem during secondary hardening. Fig. 5a shows carburisation penetrating the tooth via the interconnected pore network and precipitating as the white carbides along the pore edges. Fig. 5b highlights the heavy carbide concentration along a tooth edge and shows the martensite plus retained austenite microstructure in greater detail.

Illumination of the specimen

During the examination of both the as-polished and etched/stained surfaces, the light used to illuminate the specimen should be capable of reflecting all information from the prepared surface. When the features of interest have a characteristic

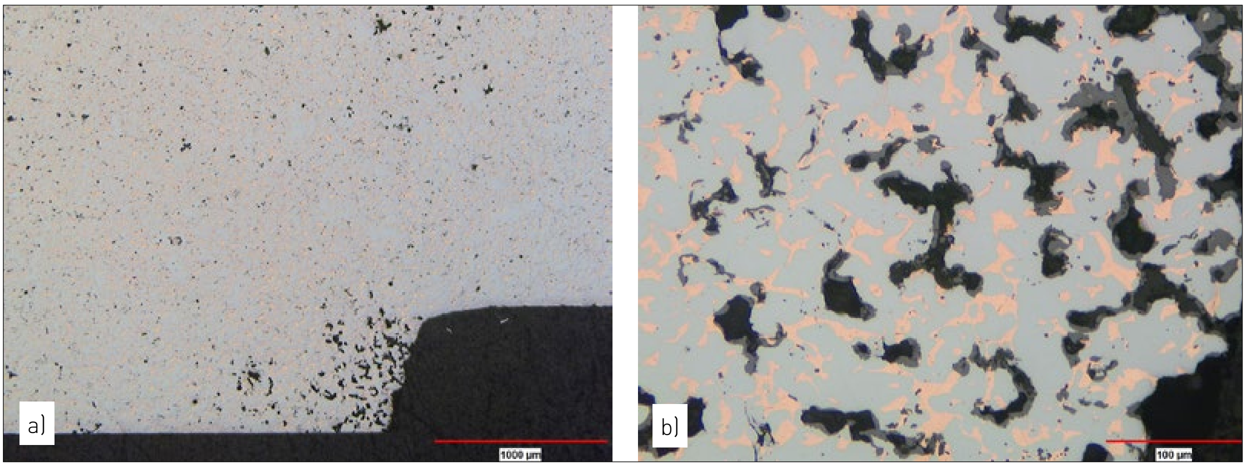


Fig. 4 Cu-infiltrated part with an oxidation plus open porosity defect in the bottom corner of the section a). Detail of the defect with copper and oxide in the pore structure can be seen in b) (unetched)

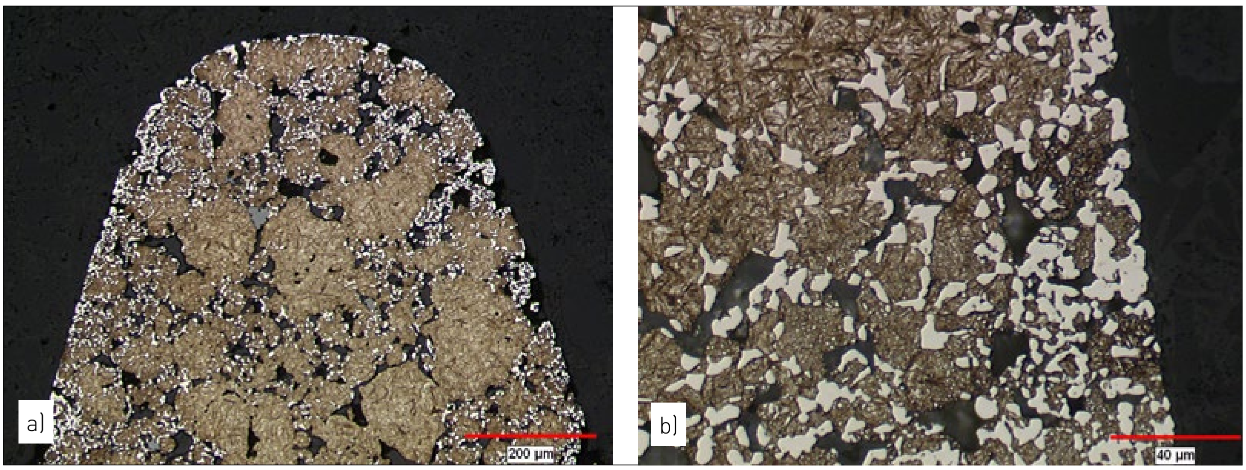


Fig. 5 Carburised gear teeth showing the locations of the high carbon content as the white precipitated carbides. In a), the tooth surface and pore edges are shown to be more heavily carburised than the interiors of the powder particles. Detail of the carbide concentration at the surface and the martensite plus retained austenite microstructure in the matrix is shown in b) (2 vol.% nital + 4 wt.% picral)

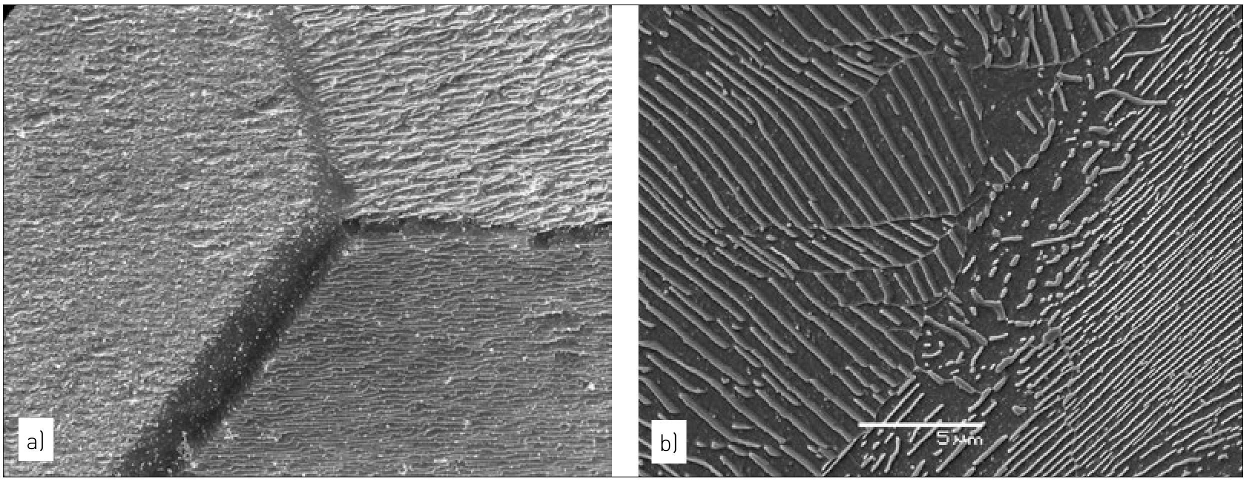


Fig. 6 Effect of an etchant on ferritic and pearlitic microstructures. In a), the etchant has dissolved the surface of three grains at different rates, which were controlled by the orientation of the grains. The pearlite in b) is revealed by dissolution of the ferrite (dark gray background), while not affecting the carbides (series of white and light gray lines). Both a) and b) are secondary electron images a) aqueous ammonium persulphate b) 4 wt.% picral

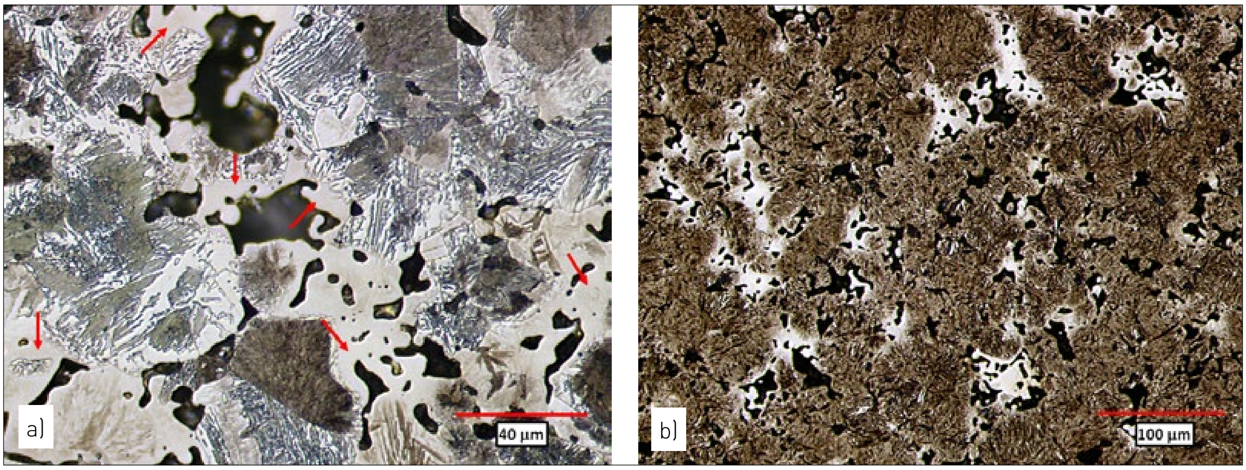


Fig. 7 Hybrid alloy with a 0.85 wt.% Mo prealloy base + 4 wt.% elemental Ni + 0.5 wt.% graphite (FLN4-4405). Image a) as sintered; Image b) quench-hardened & tempered (2 vol.% nital + 4 wt.% picral)

colour, the particular colour must be contained in the light used by the microscope in order to be reflected back to the viewer. Historically, when most imaging and documentation was monochrome (black and white), the microscope light was filtered to enhance contrast between features due to the fact that all information was recorded as shades of grey. More recently, digital colour imaging is used in the majority of laboratories and the colour information contained on the sample surface is usable by the analyst. Consequently, the light used for viewing and documentation is usually white and contains the full visible spectrum.

Chemical etching

Chemical etching is an electrochemical process where the microcells in the microstructure control the local activity of the etchant with the prepared surface. These cells contain small anodic and cathodic regions that are affected to varying degrees by the etchants. The cells are caused, not only by differences in composition (both chemical and microstructural), but by irregularities in crystal structure, grain boundaries, cold work or deformed regions, passivated layers, etc. In looking at the metallic portion of the microstructure, the relative positions of the phases and crystalline regions in the EMF series or the potential of the microcell determine the activity of the prepared surface with the etchant. This chemical activity creates microstructural contrast and causes the microstructure to be exposed. Examples of this are in seen in Fig. 6 as a ferritic material, Fig. 6a, where the variation in crystal orientation determines the rate of solution by the individual grains and with pearlite, Fig. 6b, where the ferrite is dissolved by the etchant and the carbides remain unaffected.

Revealing the microstructure

The chemical etching process used to reveal the microstructure in PM alloys is the same as for other metallic materials. With ferrous PM alloys, the transformation products are the same as those seen in wrought and cast steels. Ferrite, pearlite, bainite, martensite and retained austenite are observed, although their distribution in the part volume may be somewhat different due to the locations and distribution of the alloying additives. As was discussed earlier, some of the peculiarities observed with PM alloys derive from the methods and materials used for alloying. High additive concentrations sometimes result in alloy-rich areas, such as the Ni-rich regions observed in admixed or diffusion-alloyed powder mixtures made using elemental nickel as an additive. The nickel particles diffuse slowly at normal sintering temperatures and often create regions that do not appear to transform during cooling. These high-nickel-content regions, as observed in Fig. 7, are also more resistant to the dilute etchants typically used to reveal the microstructure and appear as flat, featureless or nearly featureless regions (see arrows) in Fig. 7a and white, unetched areas in a martensitic matrix in Fig. 7b.

The same chemical etchants and techniques are used with ferrous PM materials as for other ferrous alloys. Nital and picral are the most commonly used etchants. Excellent sources of information about etchants, such as compositions, method of application and uses are shown in the recommended reading section of this article. Of particular note are Vol. 9 of the ASM Handbook series, *Metallography and Microstructures*, and *Metallography Principles and Practice* by George Vander Voort.

Etching is normally accomplished with either a single-step application of a dilute acidic or basic solution to a freshly prepared sample surface or the deposition of an interference film (stain), which preferentially coats specific areas in the microstructure. When using the staining technique, the surface is often lightly pre-etched with a dilute acidic or basic solution before an interference layer is deposited on the pre-etched surface.

Nital – a solution of nitric acid and ethyl alcohol (ethanol)
Reveals ferrite grain boundaries and transformation products
The activity is strongly affected by microstructural orientation
2 vol.% is the most commonly used concentration for iron and low alloy steels
Concentrations as strong as 10 vol.% are used with some alloys • Safety concerns - solutions >5 vol.% must not be stored - do not use solutions >10 vol.%, they are unstable
Be aware the etchant concentration will increase over time if the ethanol is permitted to evaporate
Picral – a solution of picric acid and ethyl alcohol (ethanol)
Preferred for structures containing ferrite and carbides, e.g., pearlite and bainite • superior to nital in revealing 'fine' microstructures
Not affected by microstructural orientation
Does not reveal ferrite grain boundaries well
4 wt.% is the most common concentration
4 wt.% picral is less aggressive than the commonly used 2 vol.% nital
Safety concerns • picric acid is a solid and must be stored as a 'wet' powder or paste • do not allow the powder to become dry – the dry powder will become explosive

Table 1 Attributes of the most frequently used etchant compositions for the ferrous materials, nital and picral

When applied correctly, particular features stand out and are accentuated due to variations in the thickness of the precipitated layer. With most etchants, the cleaner the prepared surface, the more effective and uniform the etched surface.

Single step etching

The simplest and most often used etching techniques involve a single application of an etchant to the sample surface. As stated previously, the most frequently used etchant compositions for the ferrous materials are nital and picral. The two etchants are similar in their activity with the iron-based alloys, but each has strengths compared with the other. They may be used as stand-alone etchants or mixed into a nital + picral solution to realise the benefits of each. A brief listing of the attributes for the two etchants are shown in Table 1.

Examples of surfaces etched using the combination of 2 vol.% nital and 4 wt.% picral are shown in Figs. 1, 5 and 7. They illustrate the effectiveness of this combination over a wide range of alloy compositions and microstructures.

Interestingly, the copper steels present a unique set of minor problems when etched with nital and the nital-picral combination. Since the elemental copper additions become liquid at normal sintering temperatures and diffuse along austenite grain boundaries and pore edges in the powder base, these areas have the highest Cu content. When the nital etchant is applied to the surface, the Cu-rich ferritic regions respond by staining brown and do not retain the typical white ferrite appearance. The presence of the Cu also increases the speed of etching, in some cases giving the operator little flexibility in the time between having a properly etched sample and one that is over-etched. This staining can be seen at the locations indicated by the arrows in Fig. 8a, which illustrates an Fe-Cu-C alloy sintered for a time of only 5 minutes at 1120°C. This microstructure contains ferrite, pearlite, free Cu and porosity. Fig. 8b is a second example, in this case

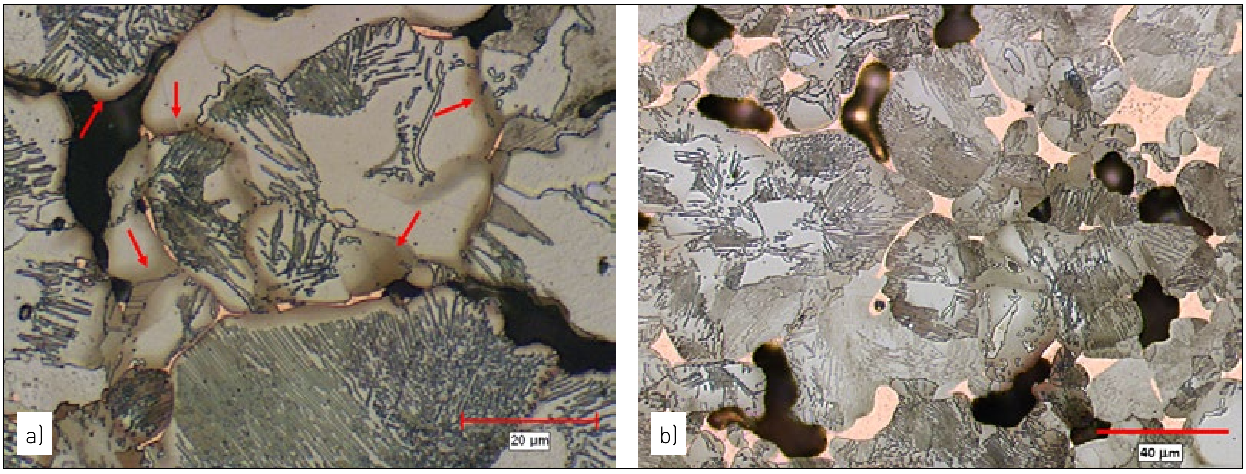


Fig. 8 Iron-copper-carbon samples showing the brown stain resulting from Cu diffusion in ferrite. Image a) sample sintered for five minutes where the Cu diffusion distances are limited due to the short sintering time and b) a fully sintered, Cu-infiltrated sample (1 vol.% nital + 4 wt.% picral)

illustrating a Cu-infiltrated Fe-Cu-C material. In both cases, the brownish staining is apparent.

The difficulties resulting from this staining include a masking of the structure within the brownish ferrite (usually pearlite or bainite) if the sample is heavily etched. The dark stain may result in a possible misinterpretation of the microstructure when examined at lower magnifications, where, if not verified at higher magnification, these brownish areas may mistakenly appear to be a fine pearlite or bainite microstructure. A change in the composition of the etchant to a combination of 1 vol.% nital and 4 wt.% picral, reducing the concentration of the etchant, gives the operator more latitude with the time needed for etching. The samples in Fig. 8 were etched with this diluted nital-picral solution to control the speed and depth of staining while revealing the pearlite accurately.

While nital and picral are the most commonly used etchants, other etchants formulated for general use or designed to reveal specific features are also used. Several of the reference books listed at the end of this article contain extensive lists of etchants and should be consulted as needs arise.

Fig. 9 An unalloyed Fe particle shown as a darkened feature in a pore-free, powder forged low alloy steel (2 vol/o nital + 4 wt/o picral then Beraha's 3-10)

Deposition of an interference layer

With PM steels, stain etching usually uses a combination of a dilute acid pre-etch (nital, picral or a combination of the two) to roughen the freshly prepared surface followed by immersion in an aqueous solution designed to deposit an oxide, sulphide, sulphate or molybdate interference layer onto the pre-etched surface. This layer appears as a controlled stain with the composition and thickness determined by the local chemical composition, transformation product, phase, microstructural/crystal orientation, exposure time, etc. at the sample surface. As the thickness changes locally, the colour resulting from interaction of the light with the interference layer also changes. Several examples are included that illustrate the use of these techniques with PM materials.

Cross-product contaminant

One of these etch/stain procedures is used to differentiate cross-product contaminant powder particles in an alloy with higher or lower alloy content. After staining, the appearance of the contaminant particles is contrasted against the matrix material. In this condition, quantitative microscopy in the form of a systematic point count is performed on the sample surface to estimate the amount of contamination

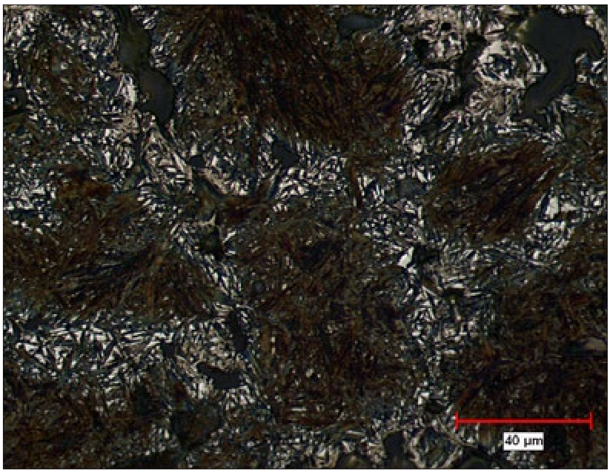


Fig. 10 Surface of a sinter-hardening alloy after accelerated cooling. The majority of the microstructure is martensite with the small, angular, white features of retained austenite located at particle and grain boundaries. (2 vol.% nital + 4 wt.% picral then 25 wt.% sodium bisulphite)

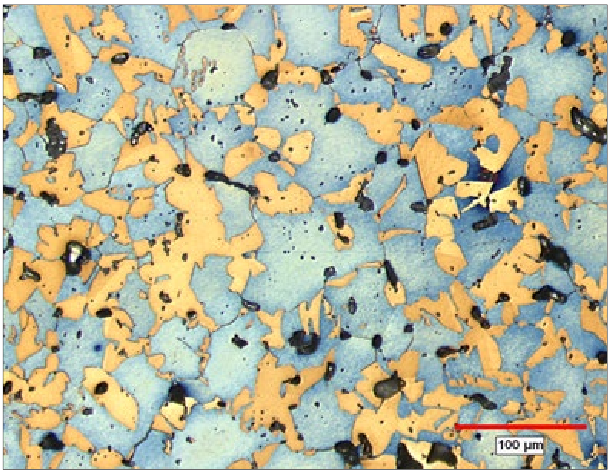


Fig. 11 Duplex stainless steel stained to separate the ferrite (blue) and austenite (tan) grains. (Beraha's II)

contained in a batch of powder. This test method has been adopted by the ASTM as a standard test method and is designated B795.

An example of an unalloyed Fe particle in a low-alloy steel powder is shown in Fig. 9. The Fe particle is stained with a heavier, darker layer and can be distinguished from the surrounding material due to the lower alloy content and correspondingly higher chemical activity (less corrosion resistance) compared with the surrounding low-alloy matrix. The thickness, and consequently the darkness of the deposited layer, is determined by the relative local chemical activity on the sample surface.

Retained austenite in PM parts

The second etch/stain example involves the determination of the amount and location of retained austenite in PM parts. The presence of retained austenite is of great interest but can be difficult to measure in PM materials. This is caused by the alloying methods and sintering processes that define the alloy distribution and, consequently, the local hardenability. The higher-alloyed areas are more hardenable and may be more susceptible to retaining untransformed austenite upon cooling.

The etch/stain procedure is used to darken the martensite while leaving the retained austenite white. The contrast between the two constituents clearly separates the features of interest (retained austenite) from the remainder of the microstructure and permits determination of both the locations and amount in the part volume. In Fig. 10, a sinter-hardening alloy with elemental additions of 2 wt.% Cu and 0.9 wt.% graphite has been sintered, then cooled with accelerated cooling. The stain darkens the martensite, with retained austenite shown as the small, angular, white regions along the pore edges and grain boundaries. These are the areas more heavily alloyed with Cu and locally higher in hardenability compared with the particle centres. No retained austenite is apparent in the centres of the larger base low-alloy particles.

Duplex stainless steel alloys

In the final example, the two phases in a duplex stainless steel are separated using a deposited stain. Duplex stainless steel alloys are a combination of austenite and ferrite that are formed due to partitioning of the alloying elements during sintering. The difficulty in performing a metallographic analysis on these alloys is that both the austenite and ferrite are similar in appearance when etched with a standard etchant, e.g. glyceregia. Both phases are white, with boundaries separating the individual grains.

It is often of interest to estimate the proportions of the austenite and ferrite in order to predict the behaviour of the alloy. To do this, the surface shown in Fig. 11 is stained using Beraha's II. The thickness of the deposit differs for each of the two microstructural constituents. When examined, the ferrite appears blue and the austenite tan. An estimate of the relative amounts of the ferrite and austenite can now be made. It should be mentioned that no pre-etch was used in this case.

Optical microscopy techniques

Another approach that can be used in metallographic investigations takes advantage of several microscopy techniques. The three methods to be discussed here utilise polarised light in different ways. In most cases, polarised light is used in the analysis of anisotropic (non-cubic) materials. These crystal structures react with the polarised light to produce characteristic colours of the sample surface and this can be extremely useful as an analytical tool. Conversely, many of the more commonly used elements in PM (Fe, Cu, Ni, Mn, Cr and Mo) have a cubic structure and using

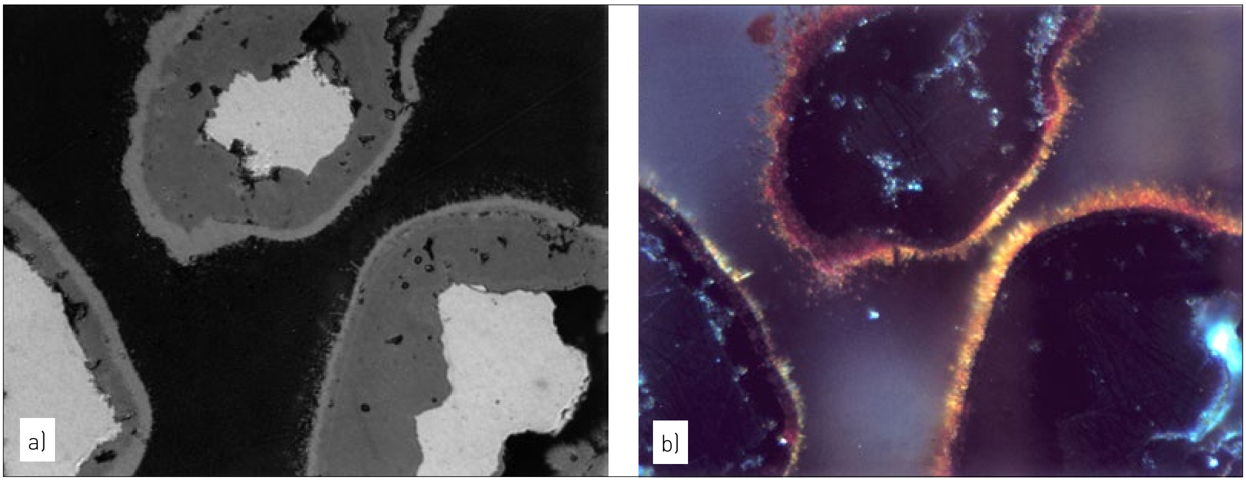


Fig. 12 Cross-sections of oxidised Fe particles illuminated using bright-field (a) and polarised light (b). The red layer on the outside of the particles is a layer of trigonal hematite (unetched)

Fig. 13 Carbon-free, powder forged, low-alloy steel processed with a two-step etch/stain. Illumination using polarised light with a sensitive tint filter (2 vol.% nital + 4 wt.% picral then Beraha's 3-10)

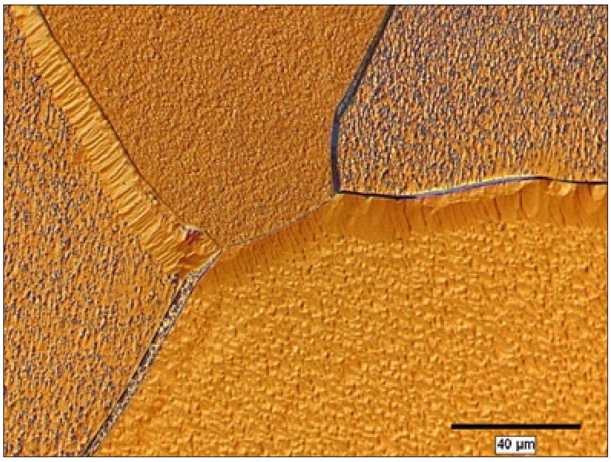


Fig. 14 High-temperature sintered Fe imaged using DIC. Portions of four grains are seen with each having a different surface texture and orientation (aqueous ammonium persulphate – DIC)

polarised light is not effective for their examination. Nevertheless, some of the compounds containing these elements are anisotropic and sensitive to the effects of polarised light.

Polarised and bright-field illumination

Fig. 12 shows a layer of hematite (Fe_2O_3) on the outside surface of several iron particle cross-sections. Although Fe is cubic in structure, hematite is hexagonal and responds to polarised light with a characteristic red colour. Image 'a' shows the metallic Fe and oxide layers using bright-field illumination. In contrast, Fig. 12b is the same field using polarised light for illumination and showing the red hematite layer.

Anisotropic interference layer

Another technique that takes advantage of the benefits of polarised light consists of depositing a layer of anisotropic material on the surface of a sample. As presented in the previous section, the etch/stain procedures deposit interference layers on the surfaces in varying thicknesses, with the relative thickness determined by several factors. The example seen in Fig. 13 is a powder forged, carbon-free, low-alloy steel (cubic) specimen with an anisotropic interference layer deposited on the surface. The variation in colour is due to orientation differences with the individual ferrite grains, shown by changes in deposited layer thickness and the response to polarised light.

Differential interference contrast

Polarised light is also used for other microscopy techniques such as differential interference contrast (DIC), where the response of the material being examined does not depend on crystal structure. In this case, the polarised light is passed through a prism before and after striking the sample and results in the ability to view differences in levels, textures, and bevels on the etched or processed sample surface. The example shown in Fig. 14 is an etched, high-temperature sintered iron where the individual grains can be seen on different levels with the texture seen as shadowed details. In some cases, the grain boundaries are displayed as tilted edges rather than well-defined 'lines' separating grains.

Safety

Many chemicals are used in the metallographic processes of preparation, cleaning, etching and staining. These individual chemicals, the combinations of chemicals and, frequently, the chemical vapours are hazardous and should be treated with both respect and proper care. The types of hazards they present are many. They may be flammable, explosive, toxic and/or corrosive, all of which pose a danger to the user. It should be remembered at all times that the use and disposal of the chemicals must be carefully and thoughtfully controlled.

Safety Data Sheets

Safety information is available for virtually all the materials and chemicals we use. This information is in the form of Safety Data Sheets (SDS) or, formerly, Material Safety Data Sheets (MSDS). Many companies, including the manufacturers and suppliers of materials and chemicals, create and revise these documents as needed. They are readily available to any interested party without charge and should be read before using any chemical or combination of chemicals. In addition to the dangers of using the chemicals, the SDS also includes precautions for chemical storage, exposure limits, and gives procedures for first aid and emergency occurrences. Although many potentially dangerous materials are used in metallography, they can and are used without incident when safety precautions are followed.

Colour coded labelling

Several organisations are excellent sources of information on the hazards of materials and chemicals. In the United States, two of these are the National Fire Protection Agency (NFPA) and the Hazardous Materials Information System (HMIS). Both have created systems which show the relative hazards of specific chemicals using a colour-coded label and numbering system. The colour-coded areas on the label show information on health, fire (flammability) and reactivity hazards, in addition to a numbering system within each colour-coded area ranging from 0 to 4, where the higher the number, the greater the hazard. The HMIS label also shows the Personal Protection Equipment (PPE) that should be worn with each potentially dangerous chemical. These labels are usually included on the SDS for a particular chemical.

Recommendations

In order to promote and encourage the safety of those performing metallographic preparation and analysis, several suggestions are included:

- Maintain accurate labelling of all stored and ready-for-use chemicals and solutions
- Use the proper storage container
- Always wear the Personal Protection Equipment (PPE) that is required or indicated for each chemical, combination of chemicals and material (safety glasses, aprons or coats, gloves, etc.)
- Use an effective fume hood and have the hood tested to ensure adequate performance
- Become familiar with the safety precautions for all frequently and seldom used chemicals
- Read all safety documents
- Use common sense.

Recommended reading

Several metallography-related references are included to provide both general and specific information on the practices of metallography. The individual volumes may not speak directly to Powder Metallurgy applications, but the basic information on sample preparation, etching, revealing and interpreting the microstructures can be useful in analysing PM microstructures.

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Author

Thomas F Murphy, FAPMI
Scientist, Research & Development
Hoeganaes Corporation
Cinnaminson,
New Jersey, USA
Tom.Murphy@hoeganaes.com
www.hoeganaes.com

Acknowledgements

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Contact:

Dr. Thomas Ebel
Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research
Max-Planck-Strasse 1, 21502 Geesthacht, Germany
Phone: +49 4152 87 1944
Fax: +49 4152 87 1920
email: pmti2015@hzg.de

Helmholtz-Zentrum Geesthacht
Centre for Materials and Coastal Research

DIRA-GREEN: Automated defect detection in green compacts to ensure quality in PM parts production

A European consortium, comprising companies and institutions, has grouped together under the acronym DIRA-GREEN for a three year project in order to develop a new inspection tool based on automated digital radiography technology for the improved assessment of green powder metal parts. Dr Georg Schlieper, a member of the consortium, outlines the design and properties of the prototype inspection system which was developed during this research.

The Powder Metallurgy (PM) industry has long recognised the need for a reliable method to inspect parts and detect local defects in the green state. The ideal test should be non-destructive, fully automatic, cost effective and fast enough to be integrated in a parts production line.

Known inspection systems such as eddy current and magnetic bridge testing, magnetic particle inspection, acoustic resonance and ultrasonic testing can be applied to sintered parts, but fail when applied to green compacts. Optical inspection with cameras can only identify surface defects and cannot detect internal defects arising due to material porosity. X-ray Computer Tomography (CT) is a powerful tool even for green compacts, but due to the high cost of the equipment it is often commercially unattractive and it cannot be used in-line due to the long processing times.

The DIRA-GREEN project

The goal of the DIRA-GREEN project was to build a Digital Radiography (DR) inspection system that responds in real time and can be incorporated into production lines for automatic defect detection in green state parts. The quality of the manufactured PM parts should then be assured by monitoring for compacted material porosity and identifying microscopic features such as cracks. The collected radiographic images for

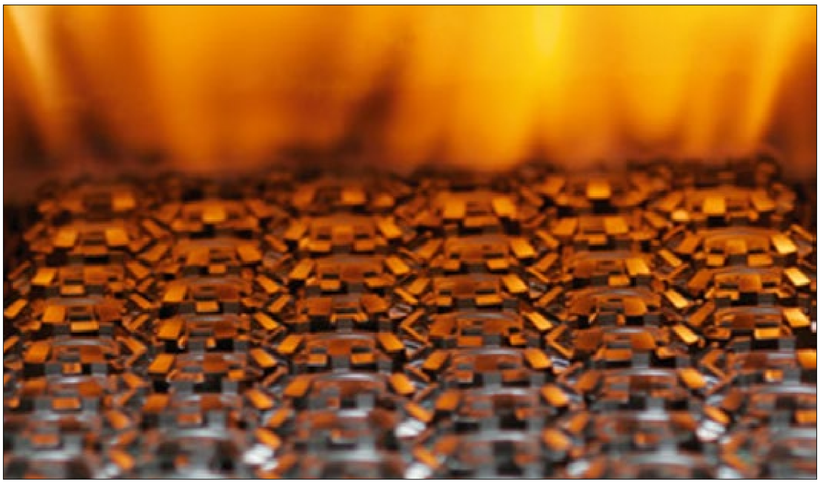

Fig. 1 DIRA-GREEN will test components prior to the sintering process

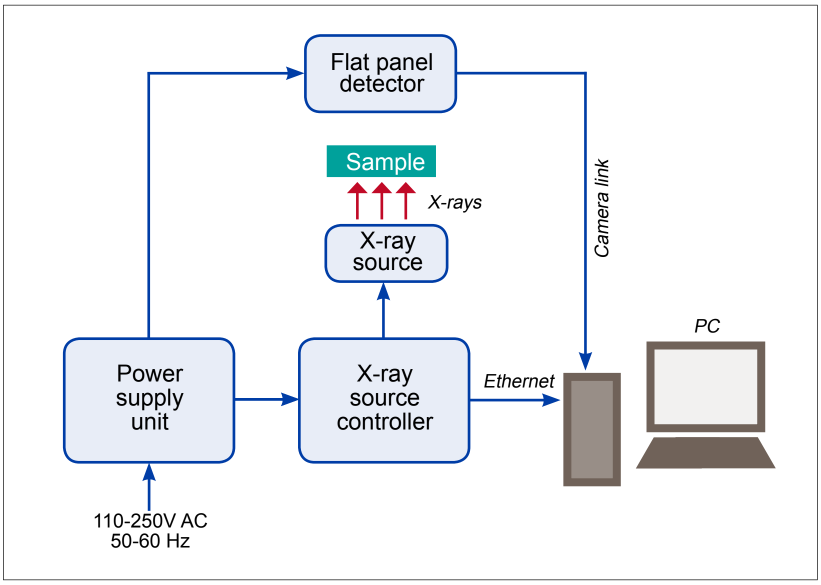

Fig. 2 Block diagram of the digital radiography system

the PM components obtained using the system should show the size and location of any flaws present. These images could then be stored in a component-linked database and would facilitate an improvement cycle for the optimisation of Powder Metallurgy mould and die designs. Also, identifying defects before the parts are sintered would allow recycling of the powder material.

Basic design of the inspection system

An integrated DR system, complete with an X-ray source controller, external PC connection, power supply unit, interlocks and warning lamps, is shown in a diagrammatic representation in Fig. 2.

During inspection a PM part is placed between an X-ray source

"The collected radiographic images for the PM components obtained using the DIRA-GREEN system should show the size and location of any flaws present."

Through the availability of a reliable and attainable inspection tool for detecting flaws in green parts the project, which received funding from the European Union's Seventh Framework Programme, would result in a substantial increase in the competitiveness of European small and medium enterprises (SMEs). It is expected that an increasing confidence in the supply of the final PM product can be achieved by improving the reliability of PM parts and reducing costs associated with the production and control of the parts.

and the digital detection media. The penetration of X-rays through the sample will depend on the X-ray energy as well as the thickness and density of the PM material under inspection. The penetrating X-ray quanta are detected using a digital X-ray detector. The detector is controlled, and images obtained, using a wired connection to a PC. As the X-rays pass through the component any changes in bulk density, due to cracks, porosity, inclusions, or simply component thickness, attenuate the X-ray quanta in proportion to the material density or thickness. The digital detector pixel elements translate the received quanta to image pixel values. The detector software shows a dense region as dark and less dense areas as light and this can be used to image any defects.

The DIRA-GREEN radiography system was arranged as shown in Fig. 3. It mainly comprises a micro-focus X-ray source emitting X-rays vertically, a sample held by a mechanical manipulator placed in line of the X-rays, and an indirect flat panel digital detector. X-ray inspection starts with a sample being illuminated by an X-ray source which is held in a fixed position statically so as not to induce any mechanical vibration and project distortion onto the detector. PM components enter the enclosure on a conveyor belt system and are positioned on a purpose built manipulator in between the source and the detector. The sample holder and the detector are mounted on a vertical translator, allowing the source-to-detector distance and the source-to-object distance to be varied to alter the magnification of the resultant radiographic image. The manipulator can also change the orientation of the PM sample with respect to the X-ray beam. The sample holding pallets have been constructed using a homogeneous material such that they do not contribute a visible structure on the radiograph, potentially masking defects.

Essential components of the DIRA-GREEN prototype

Micro-focus X-ray

A micro-focus X-ray source is an integrated solution encompassing the tube, high voltage power supply and control circuitry. It is computer controlled via the source controller, as shown in Fig. 2. The micro-focus X-ray source produces an ellipsoidal cone X-ray beam with beam angles of 120°/40°. This beam angle ensures that most parts to be imaged can be fully covered by the emitted X-rays. The degree of sharpness obtained from a radiographic image is determined by the focal spot size.

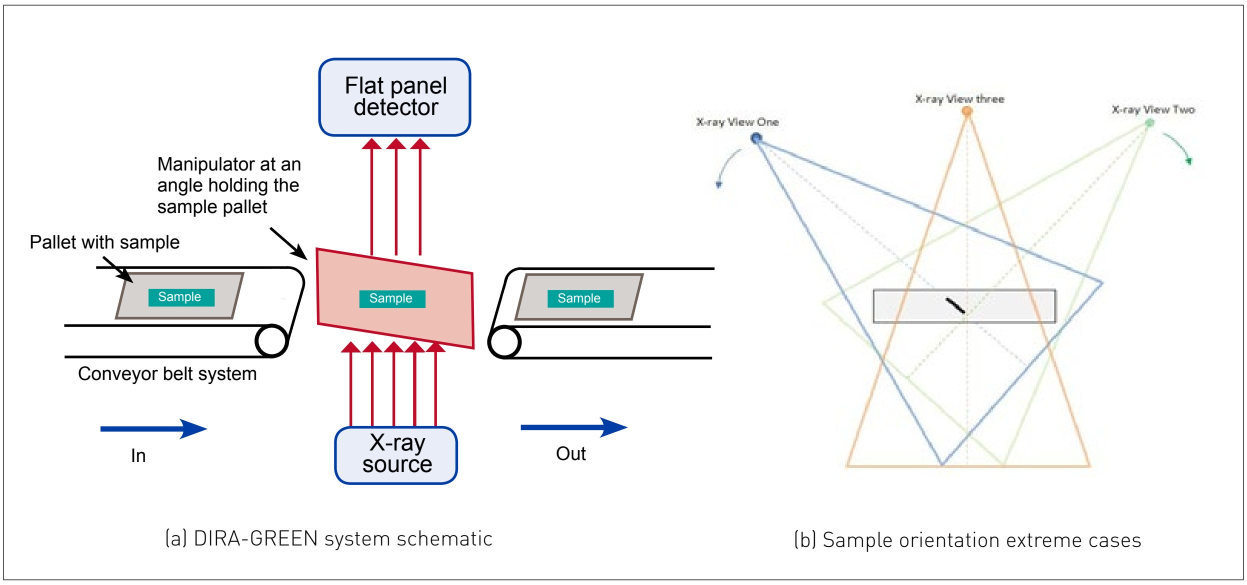

Fig. 3 Configuration of X-ray source, detector and sample pallet

The focal spot generated by the X-ray source of the DIRA-GREEN system is as small as 4 microns diameter. This is designed to reduce image blurring when compared to conventional mini-focus X-ray sources and thus provides an enhanced flaw detection capability and sensitivity. The source size contributes to the radiographic quality, influences the geometry of the inspection and sets radiographic image definition and resolution limits. With these factors in mind, as well as a detection accuracy of 0.5 mm required by the industry, an X-ray source with these specifications has been used in the DIRA-GREEN system.

Image generation

The component generating the X-ray images is a flat panel detector. For a typical 40 x 40 mm sample provided by one of the consortium end users and using 3x magnification, a detector field of view with a minimum 120 x 120 mm detection area is required. A survey was carried out in the X-ray detector supplier market to find a suitable flat panel detector. An indirect digital X-ray detector with a pixel resolution of 74.8 μm and a detection area of 145.4 x 114.9 mm resulting in an array of 1944 x 1536 pixels was chosen for the project. Fig. 4 shows the detector mounted on a frame. The detector comprises a scintillator material that converts X-rays into visible light photons, a fibre optic plate to guide the light and block the X-rays and a CMOS sensor to convert the light into an electrical charge. With exposure times of 1 to 2 seconds, the system is fast enough to be integrated in a parts production line.

Mechanical subsystem

The mechanical subsystem was designed for the manipulation of the inspected parts. The green part is placed on a pallet before it enters the lead chamber on a conveyor belt. A conveyor belt system driven by an electric motor has been constructed to accommodate specially designed pallets with interchangeable inserts to hold PM parts of varying shape and size. The conveyor feeds the parts into the X-ray chamber and presents the sample holding pallet to a customised mechanical manipulator which is located between the X-ray source and the detector, as depicted in Fig. 3a. Once inside the chamber, a manipulator takes the pallet from the conveyor and moves it into position for inspection. In order to detect non-planar defects, the manipulator allows orientation of the sample part between -45° and +45° to the X-ray beam, as shown in Fig. 3b. In addition the manipulator system allows the inspected part to be positioned such that its radiographic image can be magnified between 1.72x and 4.69x. These geometries were taken into account during the radiographic laboratory trials and optimisation. The best magnification depends on the size of the part and the size of defects to be detected. A magnification of 1.72x results in a maximum

Fig. 4 The flat panel digital detector mounted on a frame

Fig. 5 Prototype of the DIRA-GREEN PM inspection system

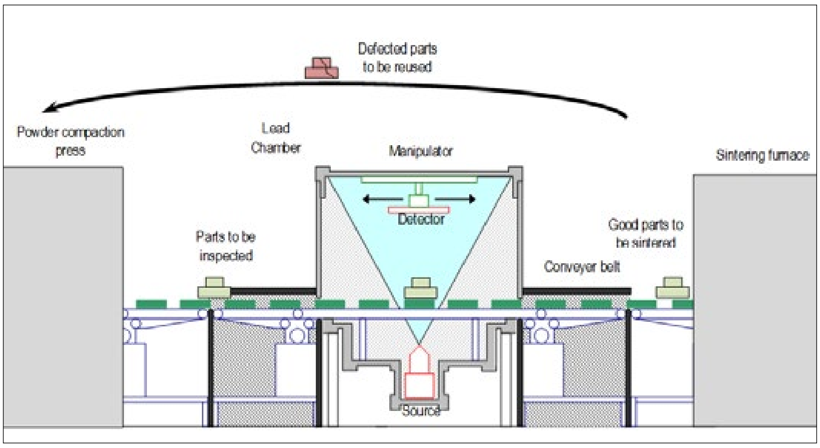

Fig. 6 DIRA-GREEN system in a PM production line (schematic)

achievable image resolution of 35 microns and a magnification of 4.69x enhances the image resolution to 20 microns.

The pallet is made of a low density, homogeneous material such that it does not significantly attenuate the X-rays, or produce a pattern on the image which could be misinterpreted as, or mask, a defect. Several images are taken and the manipulator can rotate the parts and change the aspect angle. Once the images are taken the pallet is placed back onto the exit conveyor.

The DIRA-GREEN mechanical subsystem concept has been significantly improved compared to the originally proposed system. It became obvious that because of the wide range of part characteristics a universal gripping device is not applicable. Accordingly the task to develop a universal gripping tool is in excess of the DIRA-GREEN project scope. Therefore to make the DIRA-GREEN prototype simultaneously suitable for small and fragile MIM parts and more robust PM parts, a special pallet system had to be developed.

System enclosure

The factory personnel need to be protected from the ionising X-radiation produced by the X-ray source. For this reason a lead-steel enclosure was designed and constructed to surround all components of the system and prevent the radiation from escaping to the surrounding areas. On the front side there is a windowed door turning along the horizontal axis enabling it to open in an upward direction. This door has a lead glass insertion which allows seeing inside the enclosure without the risk of exposure to X-radiation. There is also a double door at the front which locks the window door from opening while the X-ray source is in use.

The enclosure has been designed in accordance with the UK guidelines set out by the Health and Safety Executive (HSE) through their Approved Codes of Practice (ACOP), and by adherence to 'The Ionising Radiations Regulations 1999 (IRR99)' made under the Health and Safety at Work Act 1974. A warning lamp tower is fitted ensuring that information about the state of the system is communicated to personnel in the vicinity, and all openings are fully interlocked to guarantee that X-rays cannot be produced if a door is not fully closed. The enclosure, seen in Fig. 5, has been tested and certified for safe operation by a designated Radiation Protection Adviser.

In order for the DIRA-GREEN system to be integrated in a production line within a PM factory setting a design as depicted in Fig. 6 was chosen. Parts coming from the powder compaction press are fed by a conveyor system into the lead chamber. Inside the chamber is the radiation source, the manipulator and the flat panel detector. The inspected good parts leaving the lead chamber to the right are transferred to the sintering furnace.

DIRA-GREEN system performance

The performance of the DIRA-GREEN system was first evaluated under laboratory conditions using standard methodologies. Trials on the radiographic equipment were also carried out on the stand-alone pieces to optimise the conditions and inspection parameters in the final integrated system.

The initial equipment testing was carried out in the existing general purpose laboratory radiography bay at TWI (Wales, UK). At all times the necessary dark, gain and defect correction algorithms were processed to ensure clarity of the image. The performance of the

X-ray equipment was evaluated by quantifying the focal spot size of the X-ray source and testing the actual pixel resolution of the detector. To perform these tests two different Image Quality Indicators (IQI) were used: a specialised high resolution line pair micro-chart, JIMA RT RC-02B, for the focal spot size measurement and a Duplex IQI (BS EN 462-5) for the detector resolution.

JIMA RT RC-02B contains line pairs of varying distance ranging from 0.4 to 15 µm. The IQI was placed as close as possible to the source target to obtain the highest possible magnification in order to determine which of the micrometer-scale line pairs could still be distinguished as two lines. The radiographic images were obtained at X-ray source energies of 45kV. The 3 µm line pair was visible, as shown in Fig. 7, therefore 3 µm was inferred as the measure of the minimum focal spot size.

The pixel size of the digital X-ray detector as specified by the manufacturer is 74.8 µm. The effective resolution of the detector was quantified using a duplex line-pair IQI (contains 13 line pairs ranging from 130 to 50 micron distance) by placing it on the surface of the detector at 1x magnification. In accordance with BS EN 462-5, the first unresolved line pair is then used as a measure of the basic spatial resolution. Fig. 8 displays the radiographic image of the Duplex IQI including the intensity line profile drawn across the three smallest line pairs. It shows that 11D is the first unresolved line pair providing a measure of 80 micron for basic spatial resolution. This value is expected and proves that the pixel resolution of this particular detection is 74.8 µm.

The overall functionality and performance of the DR system was verified by inspecting PM parts with real defects. The green PM samples were inspected at a source-to-object distance that provided the greatest magnification whilst keeping the whole sample in the field of view of the detector. Experiments have been

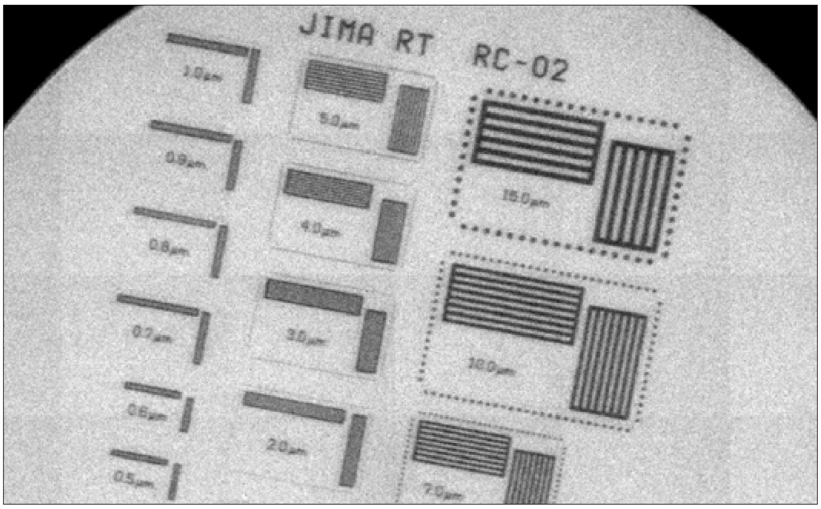

Fig. 7 X-ray source resolution: Radiograph of the JIMA micro-chart IQI Image acquired at 45 kV, 120 µA, 2000 ms exposure time, 15 fpi and 300x magnification

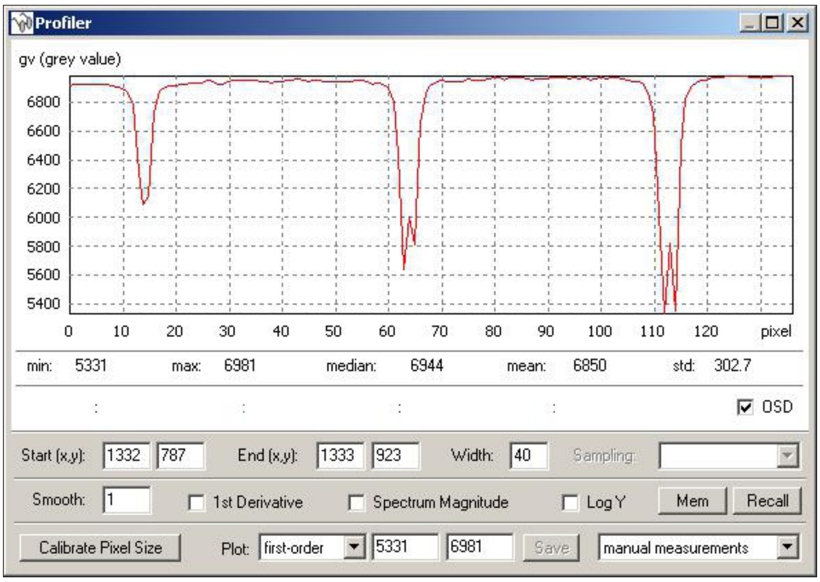

Fig. 8 Detector resolution: Demonstration of the Duplex line-pair IQI measurement. Image acquired at 160 kV, 50 µA, 500 ms exposure time, 20 fpi and 1x magnification. 11D wire measured resulting in 80 µm spatial resolution

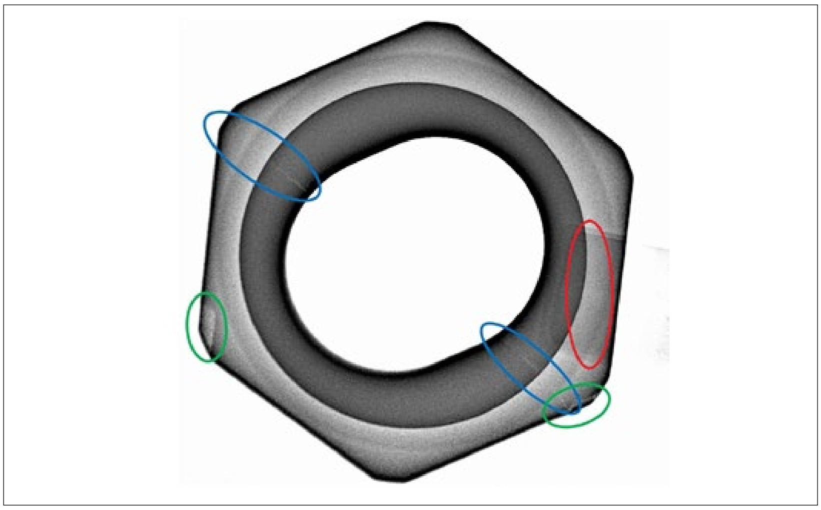

Fig. 9 X-ray image of a green PM component

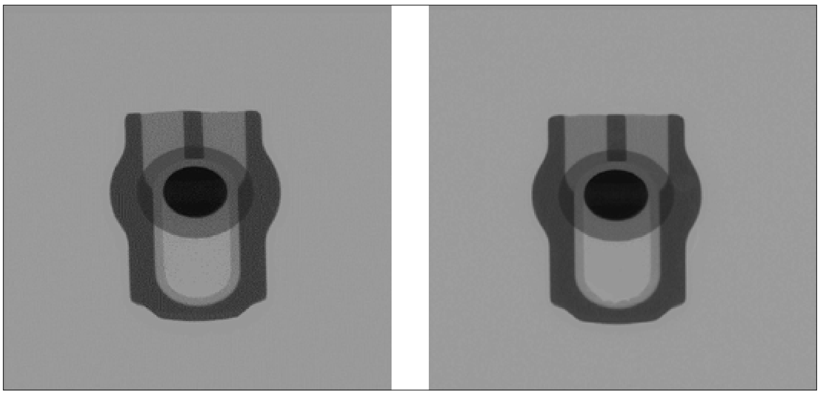

Fig. 10 Comparison of golden image (left) and recorded image (right)

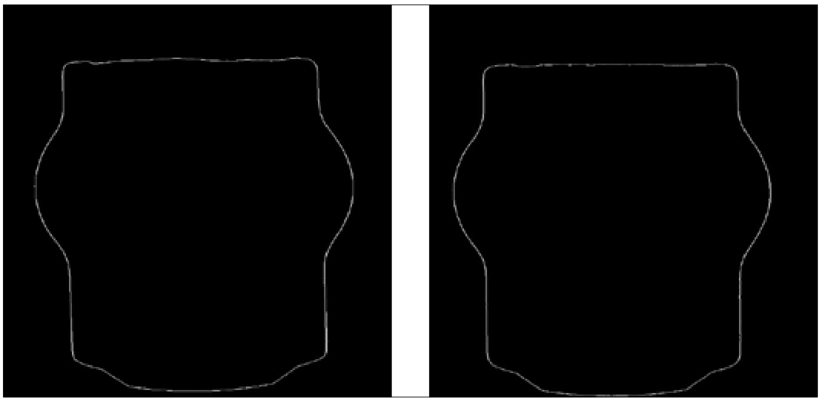

Fig. 11 Contour images of golden image (left) and recorded image (right)

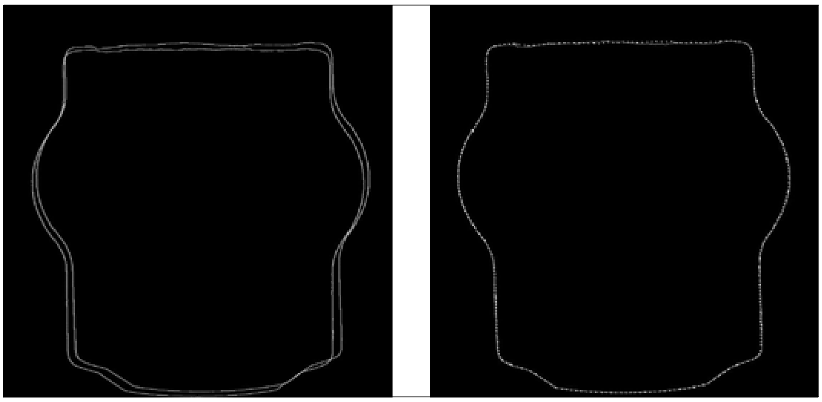

Fig. 12 Superimposed contour images (left) and aligned images (right)

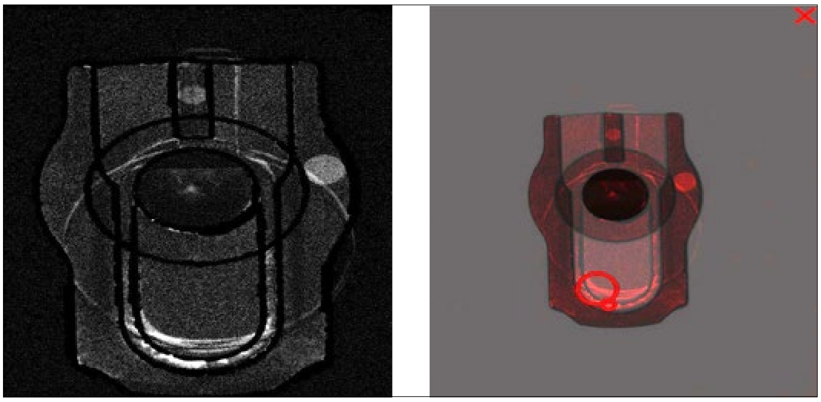

Fig. 13 Distance image (left) and final output image (right)

carried out using specific tube voltages and current, exposure times, PM sample orientation etc.

A radiograph of a green PM compact with intentionally produced defects is shown in Fig. 9. The red circle indicates a greater thickness due to the sample holder. The blue circles show a crack at the top and the green circles show loss of material on the left side edge and a crack on the right edge. The radiographic system has enabled inspection for differentiating local density changes of 2% in the PM parts as a target resolution.

Image processing

For an automatic evaluation of part defects it is not sufficient to just acquire excellent images, it is equally important that suitable software is used to evaluate the images. The task of the image processing module is to handle the images recorded by the digital radiography system and evaluate them with respect to defects. The X-ray detector produces the data in a matrix, allowing the measurement to be handled as images. Therefore, image-processing algorithms have been developed to identify discrepancies, voids and cracks within the internal structure of the material.

The evaluation software developed by DIRA-GREEN compares the recorded image of a compact to a reference "golden image" of a perfect part. To be able to detect cracks with any orientation, several images are taken with different pallet rotation and tilting offset values. For each angle a separate golden image is required and each recorded image is compared to the corresponding golden image.

Fig. 10 shows a golden image of a MIM part and a recorded image of another MIM part from the same mould with a small area of reduced density. With the naked eye it is impossible to detect the defect in the second image, however the image processing software is able to highlight this defect.

Image processing involves several

steps. The first step is required to remove the background and noise from the input images and to effectively assign the area of comparison. This is done through threshold segmentation with noise elimination. Both the recorded image and the golden image undergo this process.

One of the main challenges of the image comparison in DIRA-GREEN was that the golden image and the recorded image had a slightly different position, orientation and scale due to mechanical tolerances of the manipulator hardware. To overcome this problem, contour images are created by eliminating all information of the part bodies (Fig. 11). The two contour images are superimposed and aligned with a best fit (Fig. 12). With the new contour coordinates a remapping of the recorded image is executed.

After remapping the recorded image, a distance image is created by computing the distance between each two corresponding pixels. High intensities in the distance image identify the possible defects, as shown in Fig. 13. The purpose of generating the distance image is to create a matrix of data where each cell intensity represents a distance value from the ideal contour. A cell value is low/dark near the contour and becomes lighter as the cell is further away from the ideal value. The generated distance image is measuring how far a transformed pixel is from the golden contour. With the contour distance image the user can directly measure the position errors. The creation of this image, however, is mainly for debugging purposes.

The final step of the algorithm is to automatically highlight defect areas in the distance image. As mentioned previously a defect is a high intensity area above a threshold value. Input parameters determine the actual threshold and size values. Again threshold and size segmentation is applied to screen out valid defect areas whose parameters can be fine tuned in the training mode. Right now these parameters have been adjusted to the latest images, but it is expected that a fine tune update of these parameters will be needed during the test phase. The result is a generated output image with clearly marked defects shown in red. The total processing time of the evaluation is currently about 2 ~ 3 seconds per image.

"Further tests and fine-tuning are still necessary before commercialisation of the system which is expected in 2016"

Conclusion

Validation tests of the DIRA-GREEN prototype have been carried out in laboratory conditions. The evaluation clearly shows that digital radiography can adequately capture information on real PM samples with enough clarity to view the real defects. These results have been fed into the optimisation of the final developed DIRA-GREEN prototype, which is a self-contained, enclosed and radiation-safe digital X-ray radiography system for the automatic inspection of green PM parts.

The fact that the inspection system is enclosed means that it is ready to be used, in-line, in a PM factory. The next stage of the project is to thoroughly test the prototype during field trials in a real PM factory environment. The DIRA-GREEN system has already been shipped to the PM production site of a consortium end-user partner in order to undergo these trials. Further tests and fine-tuning are still necessary before commercialisation of the system which is expected in 2016 by the consortium.

Acknowledgements

The DIRA-GREEN research project has received funding from the European Union's Seventh Framework Programme for research, technological development and demonstration under the Capacities programme. The three year period of funding ended in September 2014.

The Consortium of the DIRA-GREEN Project consisted of:

- Ateknea Solutions (Coordinator)
- European Powder Metallurgy Association
- Associazione Italiana Prove non Distruttive
- Turkish Powder Metallurgy Association
- ALTA LAB s.r.l.
- Gammatec Engineering GmbH
- Tozmetal Ticaret
- MIMITALIA s.r.l.
- Sinterpres S.L.
- TWI Ltd
- Inovege
- IfU GmbH
- Brunel University

Contact

Gammatec Engineering GmbH
Dr Georg Schlieper
Mermbacher Strasse 28
D-42477 Radevormwald, Germany
E-mail: info@gammatec.com
Tel: +49 2195 6889274

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Innovations in Powder Metallurgy tools, products and processes at the 2014 Hagen Symposium

The Hagen Symposium, organised by the Fachverband Pulvermetallurgie, is the annual meeting for many German-speaking powder metallurgists. The 33rd symposium took place in the Civic Centre of Hagen on November 27-28, 2014, and attracted over 200 participants and some 61 exhibitors. Dr Georg Schlieper attended the symposium on behalf of *Powder Metallurgy Review*, his report covers a number of key presentations from the event as well as the awarding of the 2014 Skaupy Prize to Professor Detlev Stöver.

High performance Powder Metallurgy aluminium engine components

The target of reducing fossil fuel consumption and greenhouse gas emissions is the motivation for the development of new drive concepts in automotive technology. Hybrid electric vehicles with a main electric drive and a light and small internal combustion engine for the loading of the batteries when required, a so-called range extender engine, is envisaged as an attractive solution, particularly in urban areas. Kevin Anders of LKR Leichtmetallkompetenzzentrum Ranshofen, Austria, reported on an innovative processing route for PM aluminium alloys for applications in range extender engines.

Among the available options for internal combustion motors, the rotary cylinder engine (Wankel engine) was chosen as the best solution because expectations were to reduce the rotating masses and required counterweights and to apply energy efficient near-net-shape processes and innovative coating technologies, reducing friction and wear and improving the thermodynamic efficiency of the engine. The lower total weight and higher efficiency of the Wankel engine would lead to reduced CO_2 emissions of the vehicle.

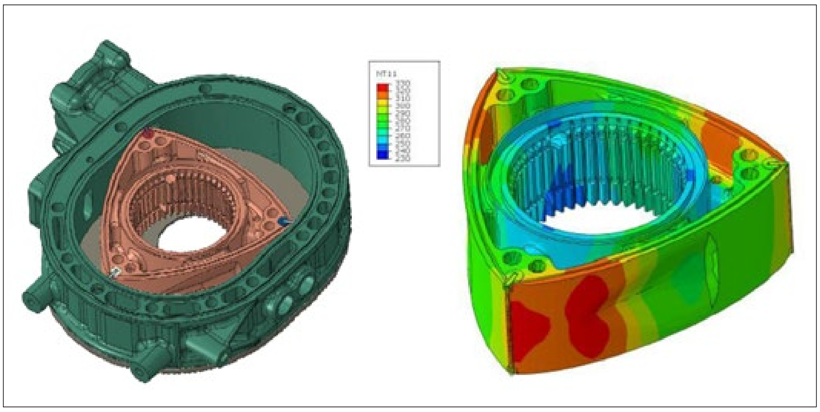

Fig. 1 Main components of the rotary cylinder engine: housing and cylinder (left) and aluminium piston showing temperature distribution during engine operation (right)

Fig. 2 Air atomised aluminium powder

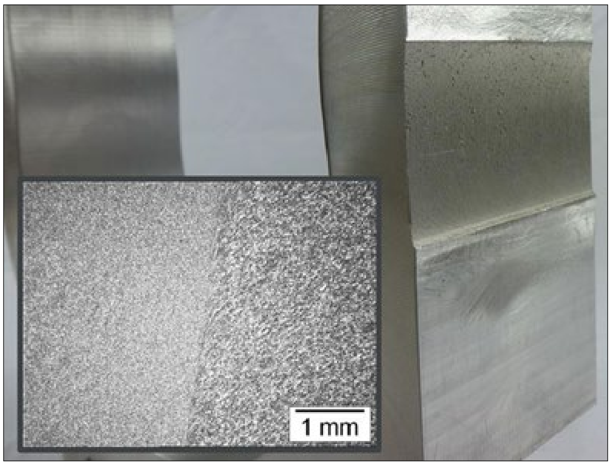

Fig. 3 Cut through the weld seam of the engine housing

Cold Isostatic Pressing

The concept for the achievement of these targets was based on innovative PM aluminium alloys for engine components, processed by Cold Isostatic Pressing (CIP) and extrusion. These materials exhibit a high thermal stability, a short process time and a flexibility for varying the length of the component. The housing and cylinder of the rotary cylinder engine (Fig. 1) are perfectly suited for this process. Fully functional demonstrator components were developed in the research project.

Air atomised aluminium powder with irregular particle shape and a maximum particle size of 400 µm was used as raw material (Fig. 2). Billets for extrusion were CIPed and machined to 305 mm diameter and 750 mm length. Prior to extrusion, the billets were completely through-heated to 450°C for 12 hours and the required profiles were produced by direct extrusion with a force of 40 MN.

The alloys investigated in the project were AlCu2Mg1.5Ni (Al2618), an alloy with excellent mechanical properties up to 300°C, and AlSi12Cu (Al4041), an alloy exhibiting high wear resistance and also good mechanical properties at elevated temperatures. The extrusion parameters were optimised depending on the alloy composition.

Friction Stir Welding

The housing could not be extruded in one piece due to its size and geometry. It was, therefore, split into two parts, which led to a simplification of the tooling and reduced extrusion forces. However, an additional process was necessary to join the two halves. The joining technology of choice was Friction Stir Welding (FSW), because the processing conditions represent the best option for the prevention of the formation of cracks and pores in the weld seam. During FSW, the faces of the two components are heated by mechanical friction, but the temperature remains below the melting temperature. Occasional pores were observed at the edges of the weld seam and these were attributed to compressed gas inclusions that could expand while the material was in the hot forming temperature range, because these areas were under less pressure than the centre of the weld.

A specially developed fixture was used for FSW that could absorb the high forces required and ensure that the final position of the two halves was held with high precision. The resulting weld seam is shown in Fig. 3. The weld zone exhibited almost the same structure as, and consequently no significant change of properties from, the base material.

High wear resistance surface finish

The surface finish for high wear resistance on the rotary piston was applied by a plasma-electrolytic process forming an alumina layer. The parts were connected as the anode and immersed in an alkaline electrolyte. Then a pulsed plasma was generated at the part surface and this led to an intensive discharge of oxygen ions building up a firmly adhering alumina ceramic layer. The structure of the ceramic layer was porous on the outside and dense on the inside. This layer offers superior hardness, resistance to wear, corrosion and heat and, at the same time, is able to incorporate a lubricant.

Coating trials showed that, although both alloys Al4041 and

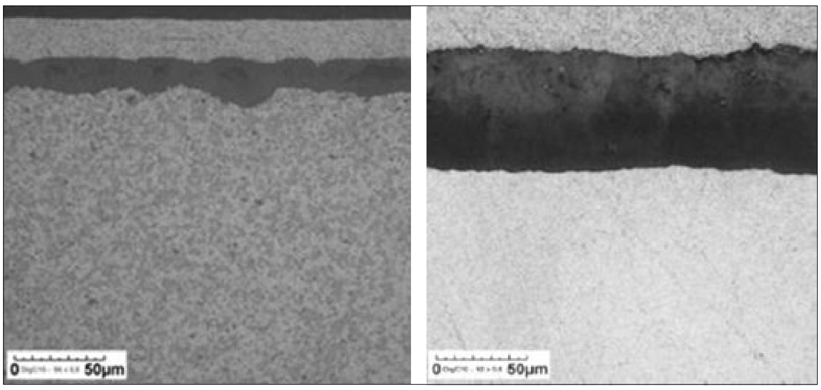

Fig. 4 Structure of oxide ceramic coatings on Al4041 (left) and Al2618 (right)

Al2618 could be successfully coated, the growth of the layer was significantly slower on Al 4041 (11-42 µm) than on Al2618 (63-71 µm). The coating thickness on Al4041 varied to a greater extent and the porosity was higher (Fig. 4). This was interpreted as a consequence of the silicon content of the alloy, which leads to the formation and integration of silicon oxide in the ceramic layer.

Extensive tribological tests were performed in order to find the best combination of materials. Laboratory tests, both with and without lubrication, showed that several materials were found with much lower friction coefficients on the ceramic counterpart than the most commonly used material 100Cr6 on a Ni-SiC coating. One successful material was tungsten carbide, but details regarding the other materials were not published. The researchers are confident that the prototypes will successfully pass the next step, i.e. the validation in engine tests.

Kinetic spraying of metal powders

A presentation by Thomas Klassen of the Institute for Materials Technology, Helmut Schmidt University, Hamburg, discussed the topic of kinetic powder spraying.

Kinetic powder spraying, also known as cold gas spraying, can produce almost fully dense layers with thicknesses from 10 microns to several centimetres. Unlike in thermal spraying, the cohesion of the powder particles with the substrate is established in the solid state by plastic deformation during impact on the surface. Undesired phase transformations and secondary reactions can be suppressed due to the relatively low temperatures and short times of heat influence involved and by applying inert gases, so that even easily oxidised and thermally sensitive materials can be processed.

The spraying process

Kinetic spraying is relatively easy to implement. Typical process gases are nitrogen and helium and these are pressed through a convergent-divergent de Laval nozzle and accelerated to supersonic speed with pressures up to 60 bar (Fig. 5). The powder to be deposited is fed into the gas stream either shortly before or at the narrowest cross-section of the nozzle. The particles are accelerated with the gas stream and hit the substrate with a velocity up to 1200 m/sec. On impact of the particles on the substrate surface, their kinetic energy is converted into plastic deformation and heat. Depending on the process parameters and material properties, the temperature can vary between room temperature and 850°C. The process can be easily and reliably controlled in terms of gas pressure and temperature.

Process parameters must be carefully adjusted to the substrate and powder properties. A basis for the choice of parameters is the spray efficiency coefficient η. The critical spray velocity is defined as the velocity, where 50% of the particles stick to the substrate surface, and the spray efficiency coefficient is the impact velocity of the powder particles divided by the critical velocity. This is a universal quantity that indicates the additional kinetic energy available for the formation of the surface layer. The best results are usually achieved for values of η between 1.5 and 2.5. Above 2.5, the particle beam begins to erode the surface.

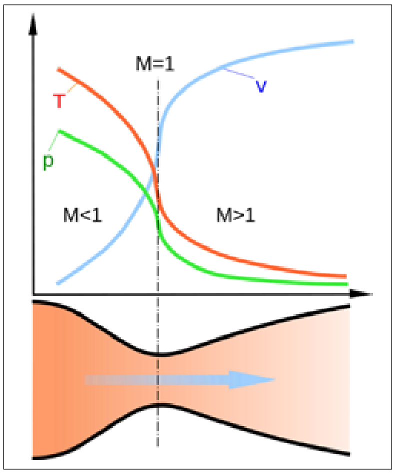

Fig. 5 Profile of a de Laval nozzle with temperature T, pressure p, and velocity v (M = Mach)

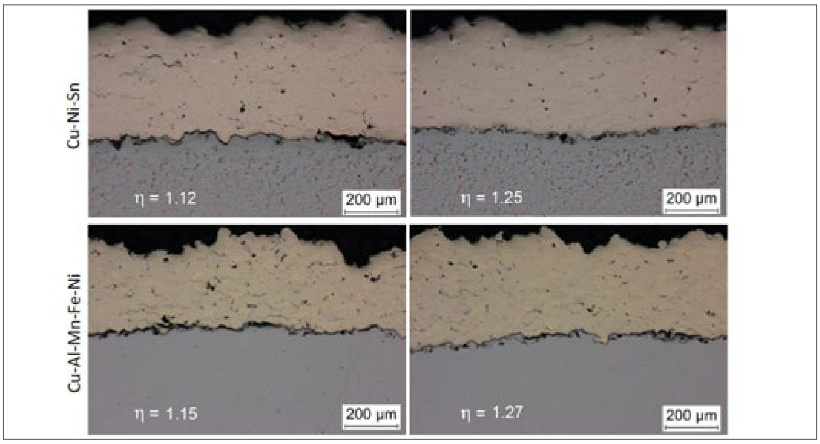

Fig. 6 Micrographs of two different kinetic sprayed bronze coatings (η = spray efficiency coefficient)

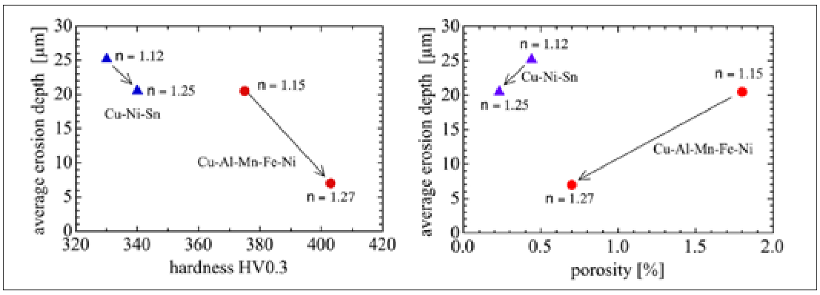

Fig. 7 Results of a 300 minute cavitation test on kinetic sprayed bronze coatings (n = spray efficiency coefficient)

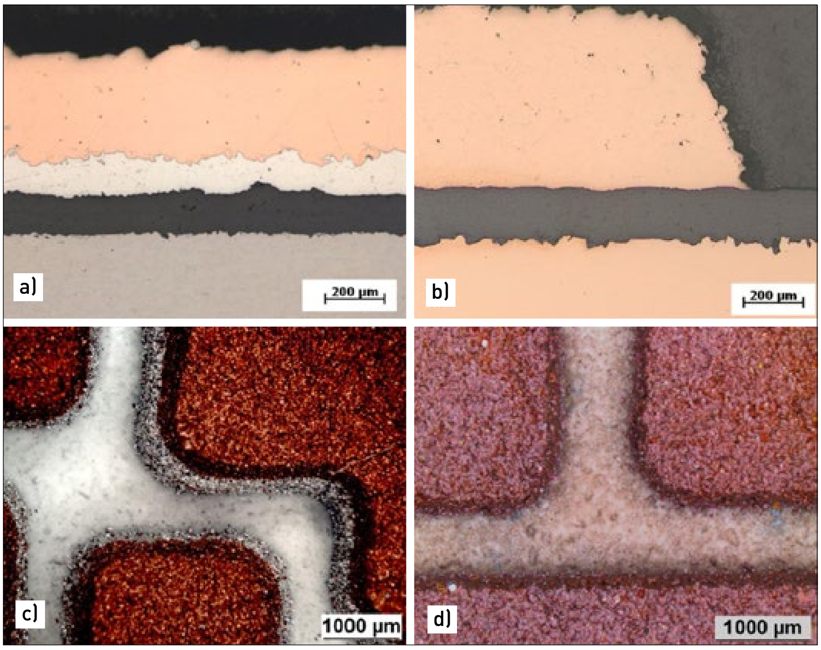

Fig. 8 Kinetic sprayed Cu on thermal sprayed Al_2O_3, micrographs (a, b) and top view (c, d); a) and c) with cold gas sprayed Al intermediate layer; b) and d) directly sprayed on preheated Al_2O_3 layer on Cu heat sink substrate

Applications for kinetic spraying
According to Klassen, kinetic spraying is very well suited to the repair of damaged parts and to the production of thick coatings and even to the generation of entire free-standing components by Additive Manufacturing. This is of particular interest for high strength materials that are difficult to machine, for example for manufacturing complex titanium components. Titanium coatings and thicker structures with less than 1% porosity and with tensile strengths of 450 MPa have been reported, using nitrogen as the process gas. After a recrystallisation anneal (800°C, 1 h) these structures achieved a fatigue strength of 93% of that of the wrought material.

The combined protection against corrosion and cavitation as well as repair work on ship propellers and rudders is accomplished with coatings of bronzes similar to those used for casting the propellers themselves (Figs. 6 and 7). Powder particles of these high strength bronzes may contain large amounts of metastable phases, such as martensites, which are too hard and cannot be easily sprayed. The normal deformation behaviour of the powder must be restored by annealing prior to spraying. It may also be advantageous to preheat the substrate in order to enhance the formability.

Another application for power electronics in future hybrid and fuel cell vehicles has been developed in cooperation with Germany's Fraunhofer Institute in Dresden. The idea is to spray the electronic circuits directly on the component housing so that separate supply cables and heat sinks are not required. The substrate is first coated with an isolating ceramic by thermal spraying. Then, the electrically conducting traces are applied by cold gas spraying of Cu powder in the desired pattern. The challenge is to achieve sufficient cohesion because the impact of the Cu particles, with the usual spray parameters, creates cracks in the ceramic layer. A cold gas sprayed intermediate Al layer (Fig. 8) can sufficiently dampen the impact.

The impact of Al particles is less critical in relation to crack formation due to the lower density of Al. In addition, the Al layer helps to bond or remove undesired adsorbates. It was found that Cu can be deposited even with higher spray parameters (p = 30 bar, T = 600°C) on ceramic substrates with good cohesion if the ceramic is preheated.

Advanced hardmetal technology for improved energy efficiency

Dr Uwe Schleinkofer of Ceratizit Austria GmbH reported on trends in hardmetal production, giving examples throughout the entire process chain including water sprayed powder blends, innovative resource saving processes and high efficiency products for wear and cutting applications.

Hardmetal powder blends are composed of WC, Co, a grain growth inhibitor and a lubricant. In order to obtain a free-flowing powder, the ultrafine particles are agglomerated in a spray drying process. At Ceratizit, a patented water based process was installed in 2002, with a production capacity of more than 3000 tons per year, where the ingredient powders are wet milled and then spray dried in a hot air counter-stream. Flammable and toxic liquids are thus avoided and the process is free from organic solvent emissions. The required investments are lower than for traditional spray drying with organic solvents and the processing costs are also lower. In addition, the quality of the granules is improved and the milling time reduced, resulting in substantial energy savings.

The water spray dried granules (Fig. 9) are characterised by an extremely low remaining moisture, a low tendency for sticking, a uniform wax distribution and excellent compressibility. After sintering, the materials exhibit a smooth surface and a fine-grained microstructure. A cutting tool of the latest generation produced from this powder, an indexable insert with 16 cutting edges, is shown in Fig. 10.

Hardmetal rods are usually produced by extrusion. Hardmetal granules are plasticised with a binder in a kneader and then extruded. A portion of the binder is evaporated in the subsequent drying process and then the products are sintered. Environmental standards require the reduction of the total carbon content in the exhaust gases of the drying process to below 50 mg/m³. In a comparative study of several options, it was found that regenerative thermal post-combustion was the best solu-

Fig. 9 Water spray dried hardmetal granule of 150 µm diameter (SEM)

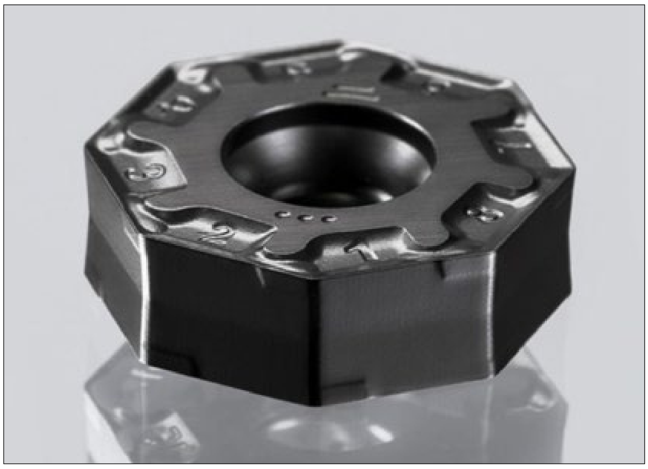

Fig. 10 New generation cutting tool with 16 cutting edges

tion in terms of CO_2 balance, process stability, required space, investment cost and energy efficiency. An energy efficient post-combustion facility was subsequently designed and installed, which successfully met the required standards (Fig. 11).

The hot air coming from the drying ovens is carried into a combustion chamber, where it flows through a ceramic honeycomb structure and is heated to a temperature where organic substances in the exhaust air are oxidised. When the process is started, it needs to be supported by a fuel gas burner, but, as soon as the concentration of organics in the air is high enough, the process supports itself thermally with the heat generated. The purified air enters into another chamber, where it is cooled down and the thermal energy is recovered. This process is energy efficient and environmentally friendly.

Self-sharpening saw

Circular saws are usually made from steel discs on which the cutting teeth segments are fixed by brazing or resistance welding (Fig. 12). For woodcutting, these segments are usually made from hardmetal. The service life of circular saws for cutting coated wooden chipboards in the furniture industry is limited by the wear of the cutting edges, which leads to increased forces and a deteriorated quality of the cut face. It is, therefore, common that cutting tools are regularly dismantled in order to restore their initial sharpness by resharpening. For many saw types, this can be repeated up to ten times.

Every resharpening action consumes resources such as energy, cooling water, grinding discs, etc., causes idle time and may produce waste during the restart of the production line. An overall cost analysis for classical circular saws revealed that the resharpening costs amount to 100-200% of the original procurement costs. If resharpening could be avoided, a remarkable potential for savings of costs and resources could therefore be made accessible.

Based on these considerations, a special cutting segment for woodcutting was developed that makes re-sharpening dispensable. Furthermore, saw producers should be able to process the new segments with their established manufacturing technologies without having to make investments. This goal was accomplished by a change from the traditional monolithic structure of the segments to a laminated structure (Fig. 13). The new cutting segment combines an easily grindable hardmetal as the base material with an extremely thin coating of

Fig. 11 Post-combustion drying oven at Ceratizit in Reutte, Austria

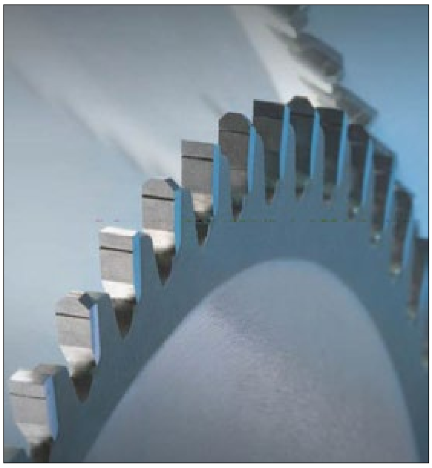

Fig. 12 Circular saw for wood cutting

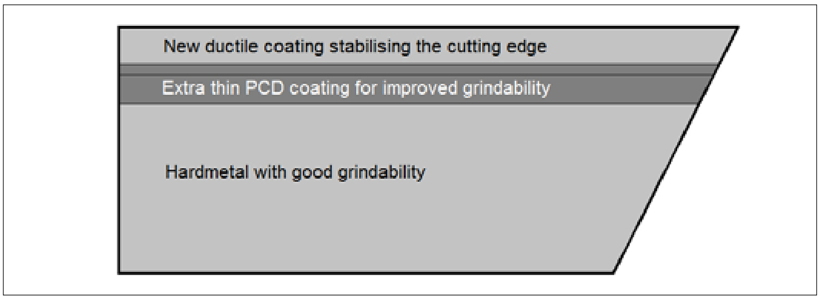

Fig. 13 Laminated structure of a self-sharpening cutting segment (schematic)

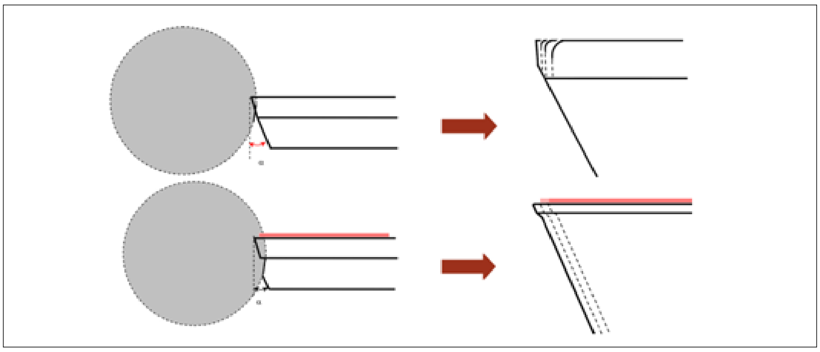

Fig .14 Wear mechanism at the cutting edge of a conventional monolithic tool (top) and the new laminated tool (bottom)

polycrystalline diamond (PCD) and a thin ductile metallic coating. The advantage of the PCD layer is that grinding can be applied instead of costly EDM machining. The metallic coating improves the stability of the underlying PCD layer against fracture at the cutting edge.

The principal difference in the wear mechanism between the conventional monolithic tool and the new laminated tool can be seen in Fig. 14. The cutting edge of the monolithic tool becomes ever more rounded, whereas the new tool remains sharp because the cutting edge is the hard PCD layer which is always exposed as the relatively softer supporting material wears faster. This constant sharpness is, however, paid for by a comparatively high cutting edge offset, which is also due to the small thickness of the PCD layer. The superior performance of these tool segments has been confirmed in laboratory tests and several months of end-user trials. The results show that, with innovative material solutions, it is possible to develop better cost- and resource-efficient sawing tools.

High temperature corrosion in sintering furnaces

Continuous high temperature furnaces often incur considerable maintenance costs due to corrosion on conveyor elements and muffles. Gerd Waning, from gas supplier Linde AG, reported on the most common type of high temperature corrosion and ways to avoid or minimise it by controlling the furnace atmosphere. Waning focused on carbon pick-up because this is the initial stage of metal dusting, the most frequent form of high temperature corrosion in sintering furnaces.

Metal dusting

Metal dusting occurs after heavy carburising of steel, nickel and cobalt alloys in atmospheres with a high carbon potential. It is particularly pronounced in the temperature range between 400 and 800°C with the maximum being reported at approximately 575°C. The muffle and belt material disintegrates into a powder mix of carbon and metal particles. The powder can be carried away by the streaming furnace atmosphere and be deposited in certain areas of the furnace (Fig. 15). In extreme cases, these deposits can obstruct the conveyor mechanism or reduce the cross-section of the muffle. The corroded elements usually exhibit dimples and holes in the metal surface (Fig. 16).

With a little simplification, metal dusting can be described as follows. High temperature resistant alloys are protected by a passive surface layer, mainly metal oxides. Where the passive layer has defects, carbon in the furnace atmosphere penetrates into the surface and forms metal carbides $M_{23}C_6$, M_7C_3 and MC (M=Cr, V, Fe, Ni). Where the solubility limit for carbon is exceeded, metastable carbides M_3C form at the surface and on grain boundaries. With further supply of carbon, the surface carbides disintegrate into metal particles and carbon. Finally, more carbon is deposited on the surface of the metal particles in the form of soot.

Suppression of metal dusting

The key to the suppression of metal dusting is consequently to control the carbon potential in the furnace atmosphere. In CO containing atmospheres, the carbon potential is determined by the Boudouard equilibrium between CO and CO_2 and the humidity H_2O vs. H_2. The CO and CO_2 contents can be measured with an infrared spectrometer, the humidity with a dew point hygrometer and the H_2 content with a heat conductivity analyser. Another option is to measure the oxygen partial pressure with an oxygen probe based on zirconia.

In many furnace atmospheres, the CO concentration can be regarded as constant and then the determination of the oxygen level and temperature is sufficient to characterise the carbon level and estimate whether the protective atmosphere has a carburising, neutral or decarburising action on the materials inside the furnace (e.g. muffle, belt, parts). If required, the carbon level can easily be shifted towards lower values by adding an oxygen containing gas such as air or CO_2; higher carbon levels can be achieved by adding a hydrocarbon gas (e.g. propane). With these options, the carbon level can be well controlled. A differentiation between open and closed systems is not necessary; disturbances such as air infiltration and leakage are almost immediately reflected and can be corrected.

The problem of controlling the carburising or decarburising action of furnace atmospheres is, however, complicated by the temperature dependence of the Boudouard equilibrium. Gases containing CO tend to decompose into CO_2 and soot when cooling down from high temperatures. This behaviour is similarly observed for the carbon level, which is a temperature dependent characteristic based on the CO, CO_2, H_2O and H_2 contents of the atmosphere. Fig. 17 shows that, at high temperatures, a carbon level of 1% or more does not lead to soot, but, on cooling down, soot is precipitated.

Fig. 18 shows the effect of a CO-containing protective atmosphere in a belt furnace. The carbon level of 0.2% at the sintering temperature increases when the atmosphere cools down, until the soot limit is reached, and then soot precipitation begins. The carburising action of the atmosphere varies depending on the temperature. In this example, the parts have a carbon content of 0.5%C, whereas belt and muffle are made from steel with 0.15%C. In the high temperature zone (A), the carbon level is below that of the parts and above that of the belt and muffle. Therefore, the atmosphere is slightly carburising on the belt and muffle and decarburising on the parts without soot formation. In the heating and cooling zone (B) belt, muffle and parts are carburised and, where the soot limit is exceeded, soot is precipitated.

This example shows that the belt and muffle can be exposed to a continuously carburising atmosphere, whereas the parts are carburised in zone B and decarburised in zone A. The parts are exposed to the atmosphere only once for a short time, but the muffle and belt permanently. If the carbon level in zone A is below the carbon content of the belt and muffle, high temperature corrosion is reduced.

Fig. 15 Metal dust deposited in a conveyor belt furnace

Fig. 16 Heavily corroded element of a protective gas generator

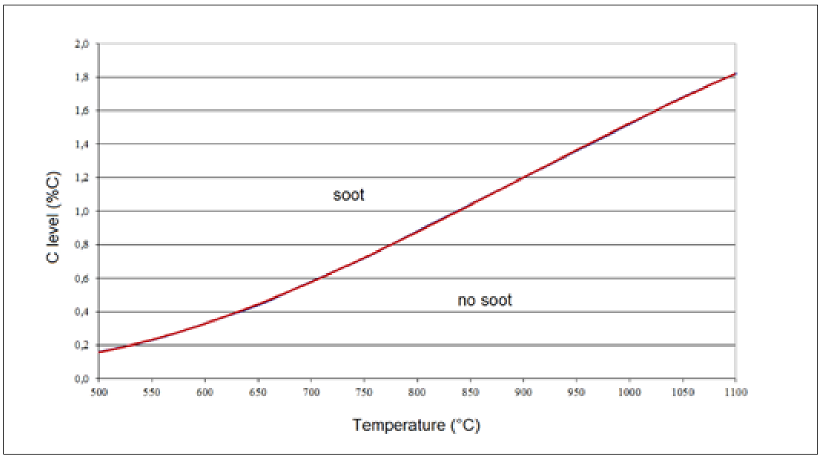

Fig. 17 Soot limit depending on the temperature

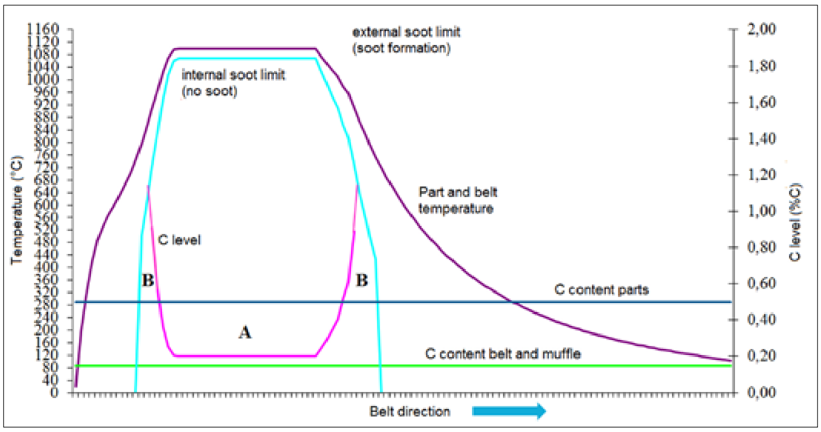

Fig. 18 Carbon level and soot limit in a belt furnace with constant gas composition (10% H_2, 2% CO, 0.0014% CO_2, balance N_2)

Preventing decarburisation

In furnace atmospheres without CO or another oxygen containing gas (e.g. N_2/H_2 mixtures), it is common to add small amounts of a hydrocarbon gas, such as propane, in order to prevent or minimise the decarburisation of the parts. As, in this case, the carbon level cannot be controlled with the test methods mentioned above, there is always a risk of soot formation and excessive carburisation of the parts, belt and muffle. Residual hydrocarbons coming from the decomposition of the lubricant may also influence the carbon balance. Waning suggested the addition of small amounts of

Fig. 19 Professor Detlev Stöver

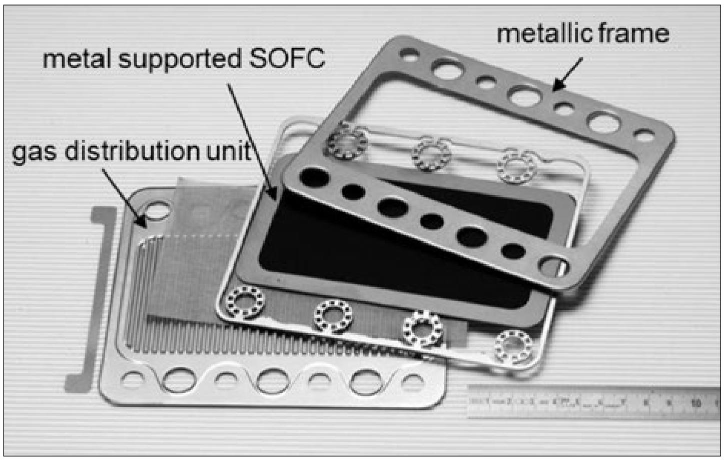

Fig. 20 Structure of a metal based SOFC

CO to the N_2/H_2/propane atmosphere, so that a continuous CO and oxygen partial pressure measurement can be applied to monitor the carbon level of the atmosphere. The carbon level can be reduced by adding air, laughing gas (N_2O) or CO_2.

The main components of the newly developed SINTERFLEX system are an oxygen probe installed outside the furnace and a CO analyser. Trial runs with the new atmosphere control system showed that a CO content of less than 1% was sufficient for a reliable control of the carbon level in the furnace atmosphere and the lifetimes of the belt and muffle were increased by a factor of at least three.

Skaupy recipient Prof Detlev Stöver highlights role of PM in the development of advanced structural and functional materials and components

The Skaupy Prize is the highest honour that the Fachverband Pulvermetallurgie confers on distinguished powder metallurgists. At the 2014 Hagen Symposium Professor Dr Detlev Stöver received this recognition.

Professor Werner Theisen, University of Bochum, introduced Prof Stöver and presented a short summary of his life achievements. Born in 1943, Prof Stöver studied physics in Aachen and began his professional career in nuclear technology at the Nuclear Research Centre, Jülich. When Germany began to abandon nuclear technology in the 1970s, his research subsequently focussed on the development of materials and components for power engineering. Prof Stöver found that thermal spraying can be a powerful tool to create functional layers and consequently he built up a technical centre for thermal spray technology. Parallel to his work at the Jülich Research Centre, Prof Stöver gave lectures in materials science at the University of Bochum. He holds 30 patents and initiated the PhD thesis work of approximately 100 students.

The role of Powder Metallurgy in the development of advanced structural and functional materials and components was highlighted in Prof Stöver's Skaupy speech (Fig. 19).

Solid oxide fuel cells

His first examples were PM components for Solid Oxide Fuel Cells (SOFC) requiring dense, oxygen ion conducting membranes on a graded structure of porous interlayers on top of a metallic porous substrate that operate at temperatures between 650 and 900°C. A special oxide dispersion strengthened Fe-26 Cr alloy, developed by Plansee under the trade name ITM, played a key role in the development. Fig. 20 gives an impression of the size and structure of the metal based SOFC.

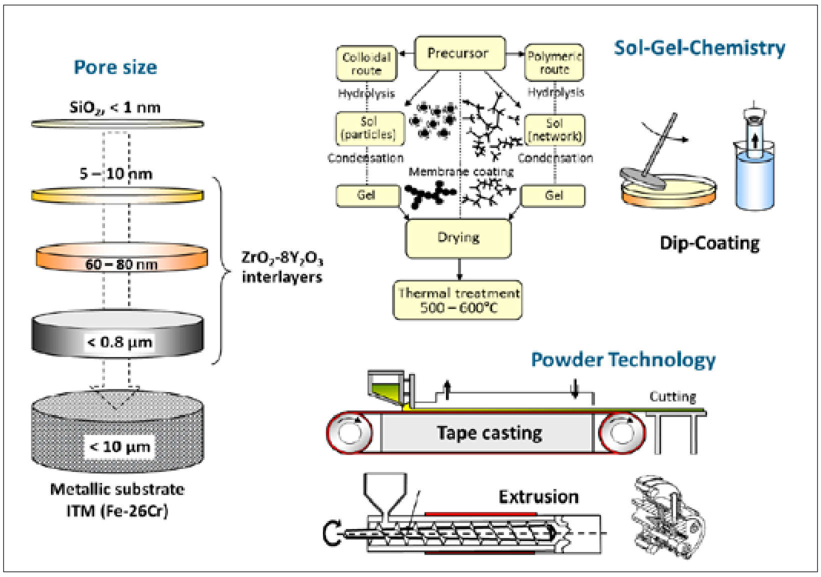

Fig. 21 Processing routes for metal based membranes

Gas separating membranes

Similar elements based on a porous metal structure, often coated with a nano-porous ceramic layer, are used as gas separating membranes. Three types of membranes are in use in the power generation sector; the post-combustion type recovering CO_2 gas from the exhaust gases of fossil fuel power plants, the oxyfuel type separating oxygen gas from air for a combustion that produces very clean CO_2 and the pre-combustion type where after coal gasification and a CO shift reaction a turbine is driven by pure hydrogen.

Alternative manufacturing processes for metal based gas separating membranes, such as sol-gel processing, tape casting and injection moulding, are shown schematically in Fig. 21. The functional layers with decreasing levels of porosity are applied on the surface. Stöver stated that the results achieved so far are not yet sufficient for mass production in terms of selectivity and permeability, but the research programmes for further improvement are continuing.

Thermal spray processes and applications

The wide range of thermal spray processes and applications covered the central part of Stöver's presentation. Coatings of metal alloys, hardmetals and ceramics are often applied to protect components in harsh environments against oxidation, corrosion and cavitation, wear and erosion, excessive heat or to prevent evaporation. For example, the efficiency of steam turbines is enhanced with operating temperatures increased to 600°C and pressures raised to 30 MPa and above and, to withstand these conditions, the chromium steel of the turbine blades is coated with Ni50Cr or WC-Co by the High Velocity Oxy Fuel (HVOF) process.

The latest developments in thermal spray technology are functional coatings of NiTi shape memory alloys. This material exhibits a specific property, pseudo-elasticity, which is particularly resistant against cavitation (Fig. 22).

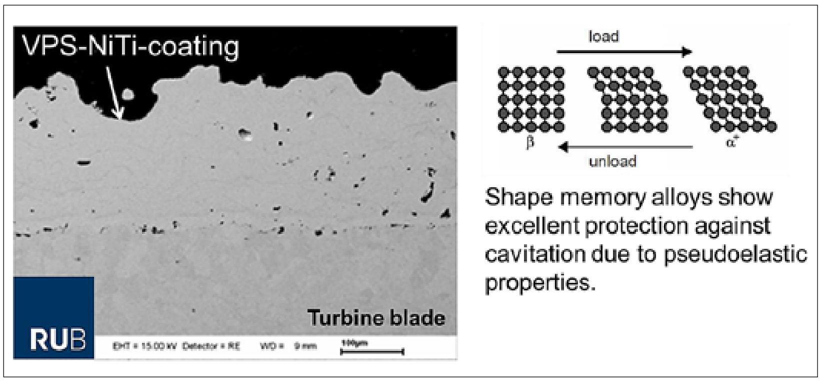

Fig. 22 Cross-section of NiTi coated sample for cavitation testing

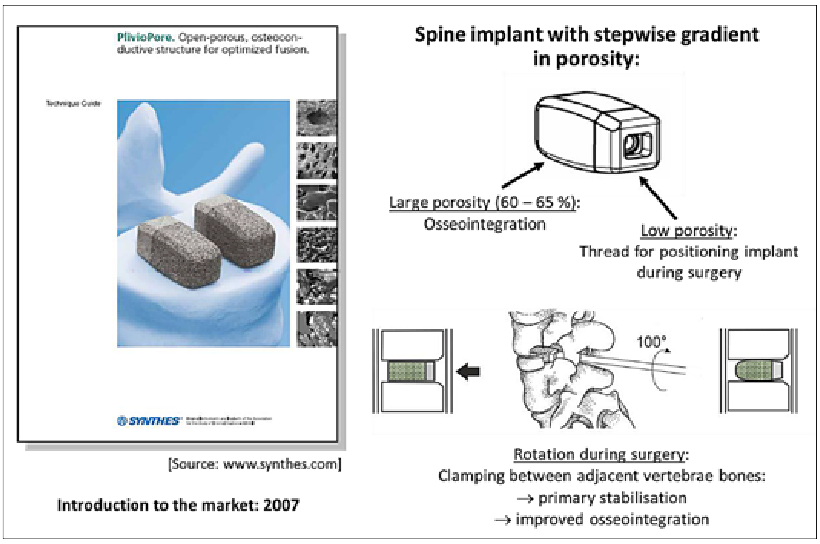

Fig. 23 Spine implant with stepwise graded porosity

Titanium biomedical implants

Due to their high strength and biocompatibility, titanium alloys are increasingly being used for biomedical implants. The best interconnection between implant and bone is achieved with high porosity titanium, exhibiting 60% porosity. The bone can penetrate the porous metal and create an ideal composite structure. The porosity does not only give the bone a mechanical key, but also reduces Young's modulus of elasticity of the implant to closer to that of the bone.

The high porosity levels of 60% and above are achieved by blending the metal powder with a space holder substance, which is eliminated in the further processing, for example ammonium bicarbonate. The pore size is determined by the size of the space holder particles.

The powder can be processed either by die compaction and green state machining or by Metal Injection Moulding (MIM). Fig. 23 shows a spine implant with a section of high porosity and a section of low porosity, which is produced by 2 component MIM.

Author

Dr Georg Schlieper
Gammatec Engineering GmbH
Mermbacher Strasse 28
D-42477 Radevormwald, Germany
E-mail: info@gammatec.com

Super Abrasive Machining: A secondary process for reducing the cost of complex component manufacture

Super Abrasive Machining is a secondary process that allows the forming of complex components from simplified sintered compacts. Through the correct adoption of the technology, savings can be made in both upstream and downstream aspects of the Powder Metallurgy process. Rocco Petrilli, President, CEO and Managing Partner of Super Abrasive Machining Innovations LLC, outlines the process and demonstrates how the technique can reduce costs and open up new possibilities for the PM industry

Secondary processes have long been seen by business, operations, engineering and finance professionals alike as necessary evils that threaten the competitiveness of their near net shaped products in the marketplace. Those employed to improve tolerance control or to improve physical or mechanical properties are begrudgingly accepted with those employed to add geometric features being found constantly out of favour.

The process known as Super Abrasive Machining (SAM) and its positive effect on the reliability and cost associated with difficult, interrupted and other heavy or complex cuts, is helping to change this perception. Since its introduction to the global PM industry in 2010, those effectively employing this secondary process are finding that, when properly placed in the PM process sequence and with appropriate consideration given to the allowable simplification of the PM compaction geometry, the process provides greater combined cost benefit than the cost of the operation itself. Additionally, tolerance control and dimensional repeatability are also enhanced.

Application of Super Abrasive Machining

As with many newly introduced processing methods, proper application is important to avoid the negative impacts of cost or performance as a barrier to market acceptance. In

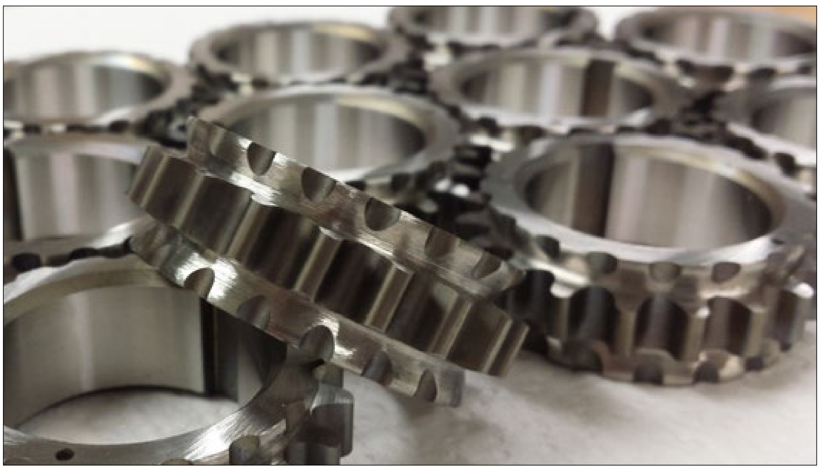

Fig. 1 Super Abrasive Machining is used to produce these detailed automotive engine crankshaft sprockets from straight sided heat treated sprocket blanks

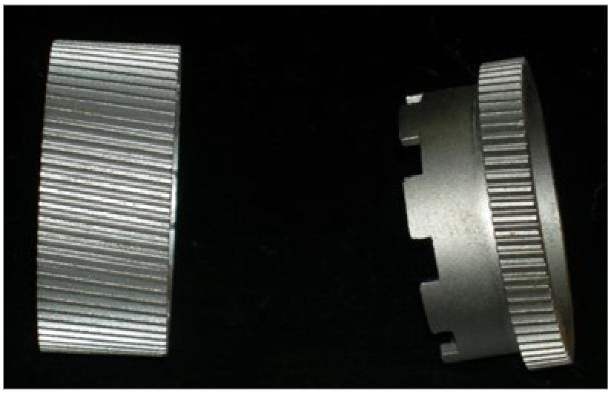

Fig. 2 Super Abrasive Machining is used to produce the helical drive gear shown right, directly from the heat treated blank seen on the left

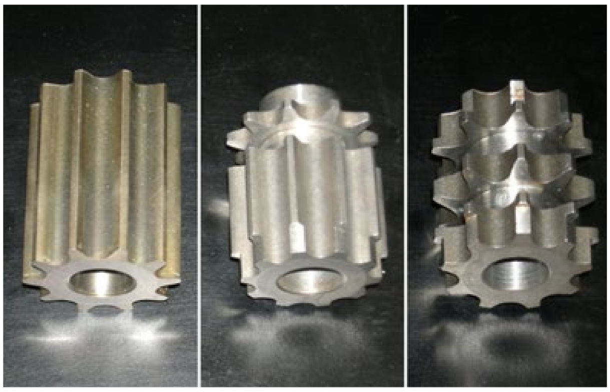

Fig. 3 The two sprockets (centre and right) are produced from the same heat treated blank (left) and show the versatility of SAM

Fig. 4 The induction heat treated blank (above) undergoes SAM as its final process step to produce the close tolerance VVT stator sprocket (below)

Fig. 5 These fine pitched 5.5 mm thick automotive sprockets are produced from straight sided induction heat treated sprocket blanks with no compromise in metallurgy or part structural integrity

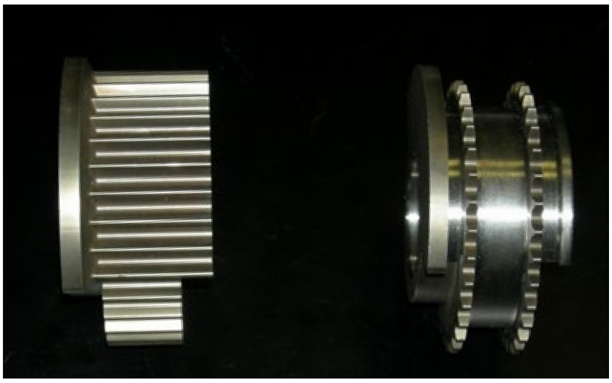

Fig. 6 Automotive VVT sprocket. Original component was made from two parts joined together. SAM enables the final component to be made from a single sinter furnace hardened component

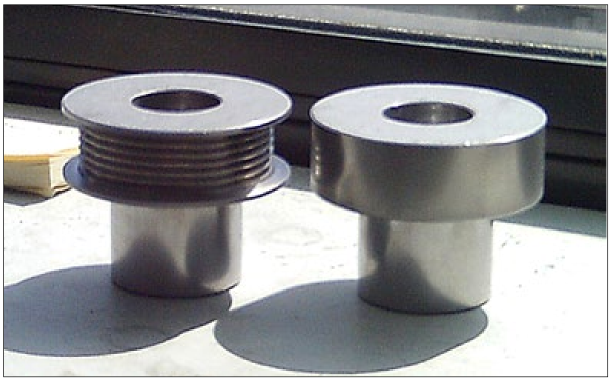

Fig. 7 V belt pulley - SAM undercut (left) and profile

view of the higher platform capital, wheel and fixturing costs associated with SAM, it is important to choose the correct applications for the technology, in order to achieve a rapid return on investment. Proven examples of the applications suited to SAM include:

- Gears and sprockets with interrupted cuts (Figs. 1-5),
- Combining geometries and converting multiple pieces into one piece construction (Fig. 6)
- Full utilisation of single-action PM pressing capacity by combining the lower burden cost of this equipment with SAM to produce features typically pressed by more expensive compacting equipment.
- Flats, straight side walls and formed slots
- Machined geometries that open additional PM conversion opportunities (Fig. 7).

The Super Abrasive Machining process

The Super Abrasive Machining process combines stock removable capabilities of grinding together with the speed, precision and cost productivity of machining. It is a complex yet reliable form of performance machining. The process is often referred to as "grinding at machining rates" as it employs an abrasive wheel, but is performed on a platform that is more akin to a horizontal milling machine than a surface grinder. It is extremely effective in enhancing the value of net metal forming processes such as PM, MIM, forging and casting.

SAM provides speed and throughput that is around 40% greater than grinding and even CNC single point turning in the soft or non-heat treated state. Table 1 shows the comparative and tangible differences between grinding, machining and the Super Abrasive Machining process.

The Cubic Boron Nitride (CBN) plated profile wheel is the heart of the SAM process. The bonded wheels are used to cut entire profiles to extremely high levels of accuracy and precision. The heavy weight wheel (up to 35 kg) with its varying diameters, coupled with spindle speeds of 5,000-10,000 RPM, provide cutting rates of up to 50,000 SFPM. These rates, along with the ability to create multiple features with a single plunge of the profile wheel, promote the distinct advantages of this process.

Proprietary coolant formulations, combined with custom fluid delivery systems, deliver coolant at high volumes to precise locations. This enables full coverage, flush and maximum cut rates and wheel life.

Custom machine tools provide CNC controls, monitoring wheel spindle speeds, vibration absorption and damping to assure uninhibited energy transfer to the work piece.

Grinding	Machining	Super Abrasive Machining
Typically a finishing operation	Both stock removal and finishing	Both stock removal and finishing
Hard or heat-treated materials	Sintered materials - Hard turning advancements - Machinability additives	Heat treated or as sintered materials - No machinability additives
High work piece pressures - distortion/damage	Tool wear and breakage	Predictable wheel wear, no breakage, low pressures – no part distortion/ damage Minimal burr issues
Slow	Slow	Highly productive
Wheel dressing required	Traditionally performed on PM to improve tolerance or add certain features	No wheel wear No wheel dressing
Costly		Grinding stock removal at machining rates
A necessary evil!	Use on interrupted cuts "because we had no other choice!"	CNC and machine features allows massive stock removal and tight tolerance finishing in the same chucking/machine cycle

Table 1 Comparison between grinding, machining and Super Abrasive Machining processes

SAM specifics:
Groove and face sprocket
PM Sinter furnace hardened
Floor-Floor cut time = 25 seconds

Tooling:
CBN electroplated wheel
$1,600.00
Average wheel life
40,000 pcs.
Tool cost/part
$0.04 each

Fig. 8 Example of costs involved using the SAM process route

Cost savings for the Powder Metallurgy industry

Cost justifications for adopting SAM extend beyond the simple comparison of costs between SAM application and alternative machining/grinding operations.

There is of course an up-front investment associated with SAM and in many of the application examples cited there is an increase in material weight and cost in the initial PM compact. However, these costs can be more than recovered from the upstream and downstream cost savings referred to in Table 2. These advantages increase in the manufacture of a component of the appropriate geometry whose compaction design is correctly influenced by the SAM capabilities.

In the case of the example shown in Fig. 8, the actual floor-to-floor cut time to SAM the two hubs on this 65mm x 18mm sprocket is 25 seconds. The resulting cost, when compared on an equivalent basis, is superior to that of single-point turning or grinding. Further analysis, however, yields the following additional upstream process cost savings:

- Increase in compaction rate of 25% - simpler compacted part configuration
- Decrease in mean press set up time of 30% - less complex tool layout
- Reduction in ongoing tool maintenance costs of 35% - stronger, more robust solid punch designs
- Downtime/press adjustment time associated with OAL adjustments, density splits, sticking tooling, part cracking etc. – decreased by 75% by factors discussed above.

Cost savings upstream	Cost savings downstream
Simpler tool designs	Reduced HT distortion
More robust tools	Lower cost compaction capital
Less complex components	Reduced in process measurement time
Lower tool maintenance	Reduced crack checking
Lower set up times	Improved quality costs – process stability
Fewer tool sets	Reduced gauging costs
Lower set up scrap	Elimination of post machining distortion
Higher compaction rates	Expanded application reach
Higher compaction process yields	Elimination of deburring costs
Reduced sintering distortion	Expanded compaction utilisation possibilities

Table 2 Up stream and down stream PM process cost reductions driven by SAM

Number of hubs	2	0	Cost difference
Downtime	\$0.162	\$0.024	\$0.138
Compaction rate	\$0.421	\$0.210	\$0.211
Initial press set up	\$0.074	\$0.034	\$0.040
Tool maintenance	\$0.113	\$0.052	\$0.061
Total Cost	\$0.770	\$0.320	\$0.450
Doubling downtime, compaction rate and press set up costs			\$0.389
Total cost savings			\$0.839

Table 3 Summary of cost savings driven by upstream process. Calculations are based on the assumption of: a work centre cost hourly rate of \$150.00 for multi action press used to compact the two hub design; work centre cost hourly rate of \$100.00 for single press used to compact the no hub design; downtime, compaction rate and press set up cost impact are doubled as the time saved on the specific example is available to produce a part of similar or greater value

Type cut	Wheel material	Micro meter	Micro inch	Ra	Stock removal
Rough prime	CBN	1.6	63	1.6	>3.3 mm
Rough	CBN	0.8 - 1.6	32 - 63	0.8 - 1.6	0.5 - 3.3 mm
Finish	CBN	0.4	16	0.4	0.1 - 0.5 mm
Fine Finish	Al_2O_3	0.1	4	0.2	<0.1 mm
Basis: Equivalent cycle times					

Table 4 Relationship between SAM wheel composition, process and component surface finish

Table 3 calculates the cost savings impact of replacement of the compaction of the two hub sprocket design (Fig. 6) with a straight sided sprocket of the entire length. The cost saving of \$0.839 calculated is 20-25% greater than the price to perform the SAM cut in the market place. Components of more complex geometry have shown this level of savings can reach 40%.

Deburring – the hidden cost

Industrial deburring is a multibillion dollar business with techniques ranging in complexity from vibratory media tumbling to chemical and thermal burr removal being employed in PM and other metal forming industries. The cost of this operation ranges from a few cents to \$0.50- \$0.60 depending on the size of the burr and geometry of the component being deburred.

Prior to the introduction of SAM, most interrupted cuts that were machined were formed by single point turning in the sintered condition. In addition to the high level of unpredictable tool breakage and machine damage caused by the impact of the interruptions, a substantial burr is created by this process. The removal process in this case is typically brush deburring at a cost of \$0.08 -\$0.18 per part depending again on configuration.

Interrupted cuts that are Super Abrasive Machined (particularly those in the heat treated state) produce, instead of a heavy burr, a sharp edge to flash of ~0.075 mm in height. While many of these components are employed in their end use without secondary deburring, others, depending on the criticality of the application, have this edge removed with media tumbling or light brushing at a cost of \$0.03- \$0.09 per part.

Developing advanced machine systems for Super Abrasive Machining

There are a number of machines available from various manufacturers that are capable of Super Abrasive Machining. However, the need for an optimised machine design that maximizes the offerings important to an effective SAM process resulted in Super Abrasive Machining Innovations LLC and Hauser Inc jointly developing the Corinthian 311™ (Fig. 9).

The Corinthian 311™, designed specifically for rapid manufacture of high volume usage automotive and industrial components, consumes 30% less floor space and produces 15% lower cycle times than traditional machines used solely in vertically integrated production.

Multiple Spindle SAM

Expanded versions of the Corinthian 311™ platform have been developed to further extend the applications for SAM technology.

The early expansion of SAM machine tool capabilities came with the development of the multi spindle Corinthian 311™ MS. Advantages of the multi spindle machine include the ability to perform OD and ID and face cuts in a single chucking. Wheels mounted on multiple spindles (shown in red and blue in Fig. 10) demonstrate the ability to provide both OD and ID cuts on the component (shown in red). The process allows exact dimensions to be achieved using a fixed set of machining data and the machine eliminates the need for additional lathe/machine capacity.

In addition to the above, the second spindle can also be employed to house a conventional vitrified aluminium oxide (alumina) wheel (inset Fig. 10) with a separate dressing unit that can be used to increase diametric control or surface finish without impacting the SAM's process ability to remove large amounts of heat treated stock at a productive rate. Table 4 explains the relationship between SAM rough cut, finish cut and resulting surface finish.

Fig. 9 The Corinthian 311™ is designed specifically for rapid manufacture of high volume usage

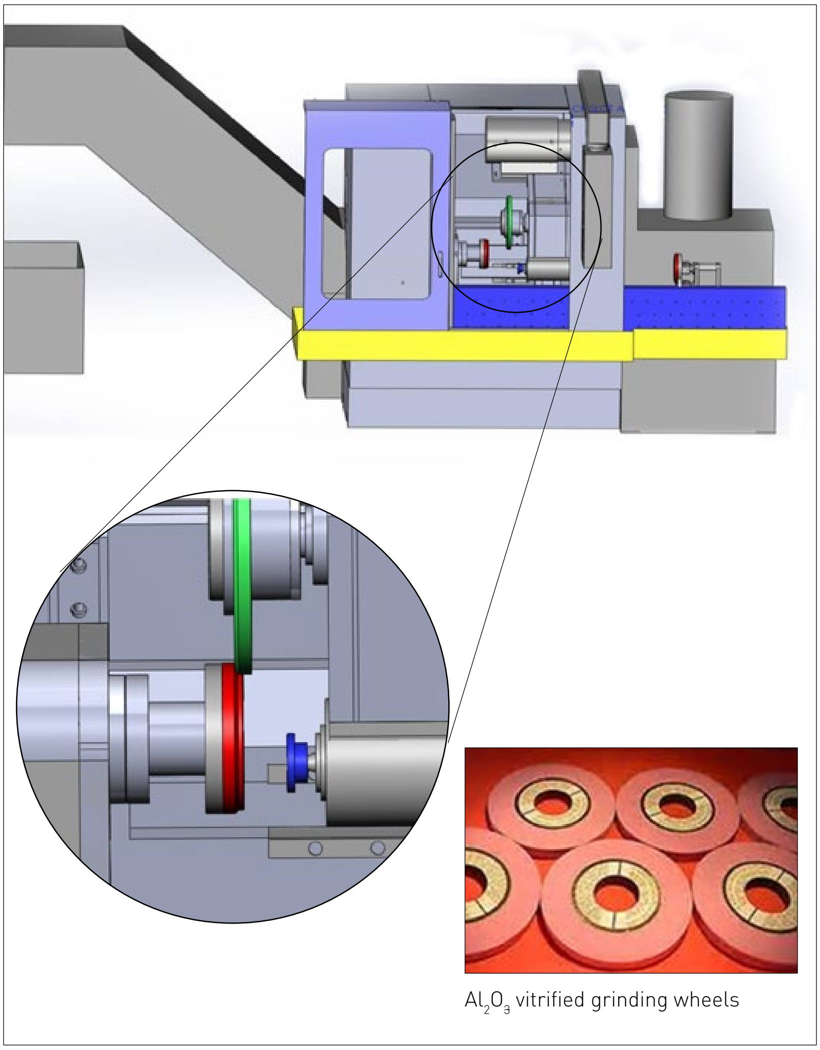

Fig. 10 The multi-spindle Corinthian 311™ MS, with the wheels highlighted in green and blue and the part shown in red. Inset shows conventional Al_2O_3 vitrified grinding wheels

Fig. 11 SAMIBORE™ components with post process bearing and bushing insertion

Fig. 12 The SAMIBORE™ process

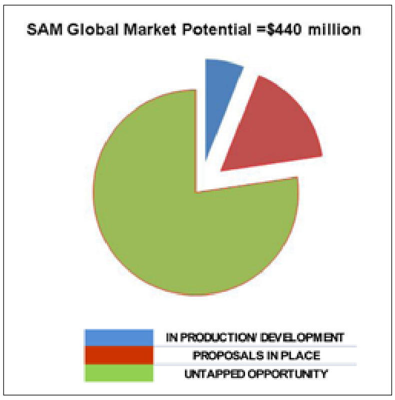

Fig. 13 Estimated global SAM market

Challenges with inside diameters

The impact of wheel diameter and rotational speed in the creation of cutting power in SAM is limited on inside diameters of less than 38.25 mm. To combat this limitation, Super Abrasive Machining Innovations LLC has combined important process and control parameters of traditional honing and SAM.

The company's 'SAMIBORE™' process (Figs. 11 & 12) has proven effective, on sintered and heat treated bores, in increasing round bore stock removal rates by 15-23% depending on final tolerance and surface finish requirements.

Summary and conclusions

Super Abrasive Machining has proven itself as both a disruptive and highly enabling machining process technology that both lowers the cost and enhances the ability to provide ever increasing geometric complexity at attractive prices. With the direct marriage of the application to the machine tool now completed, the acceptance and expansion of this technology will increase and will penetrate PM and other net shape metal forming processes with increased impact and speed.

Super Abrasive Machining remains as a virtually untapped process technology that greatly enhances PM's ability to further its offering of complex and cost effective components. The approximate global market potential and percentage of individual opportunities being addressed is graphically represented in Fig. 13.

Proper placement of the SAM process step in a PM manufacturing sequence changes each and every aspect of the process, from tool design, material selection to final deburring. The process effectively pays for itself by driving upstream and downstream cost reductions.

The compaction and deburring related cost savings are further enhanced by the processes eliminating the added costs of machinibility additives (development and additive) and resin impregnation. The elimination of machinibility additives also eliminates the inherent decrease in material strength caused by the introduction of these purposeful material inconsistencies.

The process also expands opportunities to employ sinter furnace hardening instead of quench heat treating, which further extends the upstream cost savings effect of the SAM process. By eliminating the "machine before heat treatment" paradigm and allowing for substantial stock removal economically following heat treatment, many more opportunities arise.

SAM is the only economically viable and reliable process for the forming of interrupted cuts in heat treated material.

Contact

Rocco Petrilli,
President, CEO & Managing Partner
Super Abrasive Machining Innovations LLC
20 Gillis Avenue,
Building 4 & 5,
Ridgway, Pennsylvania 15853,
USA
Tel: +1 814-772-0612
Email: rpetrilli@ppspi.com
www.samillc.com

Development of new materials and applications driving Japan's PM industry to success

The winners of the Japan Powder Metallurgy Association's (JPMA) 2014 Powder Metallurgy Awards reflect an industry continuing to develop and expand the range of applications suited to PM technology. The awards recognise innovations in new materials, manufacturing processes and component design. Evident again in this year's awards are the increasing number of applications for PM in hybrid and electric vehicles, as well as opportunities for replacing traditional production routes with more environmentally friendly PM options.

Development prize: New design

Synchroniser hub for a Dual Clutch Transmission

Sumitomo Electric Industries Ltd received an award for a low speed synchroniser hub used in a seven speed Dual Clutch Transmission (DCT) for a hybrid electric vehicle. DCTs offer a number of features including computer controlled automatic shifting and efficiency as high as that of manual transmissions, due to the absence of a torque converter helping to reduce fuel consumption.

However, weight and cost reduction are also required for DCTs because of their complex design and large number of components. To address this a high strength synchroniser hub with a helical gear form and thin wall was developed (Fig. 1). The compaction punches were divided in order to adjust the density balance of the ridges on the flange section and to rotate the punch used to form the helical gear section. Material and surface condition of the compaction tooling were optimised to prevent sticking between the bottom of the punch and the die. An exacting 19 µm tolerance of the inner diameter was achieved by using a special machining chuck to reduce deformation.

Air compressor component with thin-walled part for electric vehicle

Diamet Corporation received an award for the development of the oldham ring of a scroll compressor used in the air conditioner of an electric vehicle (Fig. 2).

In order to extend the mileage range of electric vehicles there is a high demand for smaller, lighter

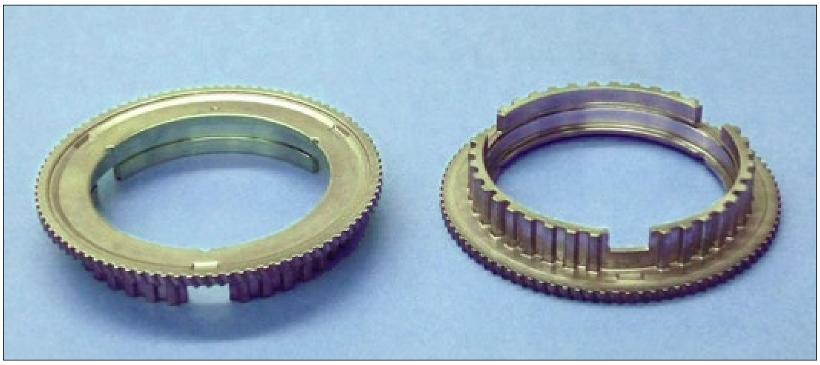

Fig. 1 A low speed synchroniser hub used in a seven-speed DCT (Dual Clutch Transmission) for a Hybrid Electric Vehicle (Courtesy JPMA)

Fig. 2 Air compressor component with thin-walled part for electric vehicle (Courtesy JPMA)

Fig. 3 A sprocket with crank sensor for use in a diesel engine (Courtesy JPMA)

Fig. 4 A sintered bearing to be used on the output shaft in an automotive door closure motor (Courtesy JPMA)

components. A 50% reduction in weight and flange thickness was required in comparison with a conventionally produced oldham ring. In addition, cost reduction was also requested by the customer.

The oldham ring was developed to be produced without machining in order to reduce cost. To achieve better flatness of the thin flange, filling conditions, sintering jigs and sizing conditions were optimised. To avoid cracks and deformation of the green compact with a thin flange during transfer, magnetic handling was utilised.

As a result, the mass production of the oldham ring was achieved and both the weight and flange thickness were successfully reduced by a half.

Sprocket with crank sensor for a diesel engine

Diamet Corporation also received an award for the development of a sprocket with crank sensor for use in a diesel engine (Fig. 3). The assembly of a sintered sprocket and a sensor made from sheet metal was replaced with the new product for the purposes of cost reduction and downsizing. Because of the integration of the components the margin for assembly was eliminated.

The geometry of the crack sensor was modified to reduce size by utilising the near net shape method of sintering. In order to avoid breakage of the small teeth during compaction, both a lubricant addition and a tooling coating were used. The high precision of the inner diameter was achieved without grinding by optimising the powder filling and sizing process steps.

As a result, the mass production of the sprocket with crank sensor for diesel engines was achieved, with the forged crank sensor being successfully replaced.

Development prize: New materials

Sintered bearing for a shaft in a door closure motor

Diamet Corporation received an award in the New Materials category for the development of a sintered bearing (Fig. 4) to be used on the output shaft in an automotive door closure motor.

An Fe based or Fe-Cu based material is the normal material of choice for sintered bearings for the low-speed and high load conditions of door closure motors. However, because of grease lubrication, corrosion of the sintered bearing was an issue. A phosphor bronze-based material was therefore developed as the material was expected to exhibit both high strength and corrosion resistance.

In this development, the contents of Sn and P were optimised to achieve high strength and hardness and to suppress deformation during sintering. However, dimensional accuracy was reduced because of the excessive volume of liquid created during sintering. Therefore, this excessive volume of liquid was decreased by optimising raw powder and sintering conditions, resulting in an improvement in dimensional accuracy.

The phosphor bronze-based material with high strength, high dimensional accuracy and corrosion resistance has been successfully developed and the mass production of the sintered bearing for the output shaft in the door closure motor has been achieved.

Valve guide material with high wear resistance generated by a dispersion of hard particles

Hitachi Chemical Co. Ltd received an award for its development of a high wear resistance valve guide material. The valve guide (Fig. 5) supports the open/close motion of valves in combustion engines. The move to smaller, turbocharged engines has resulted in higher operating temperatures and potential wear problems on the valve guides. Therefore, a higher wear resistant material for valve guides was required.

Fig. 5 Valve guides made from a new material with high wear resistance (Courtesy JPMA)

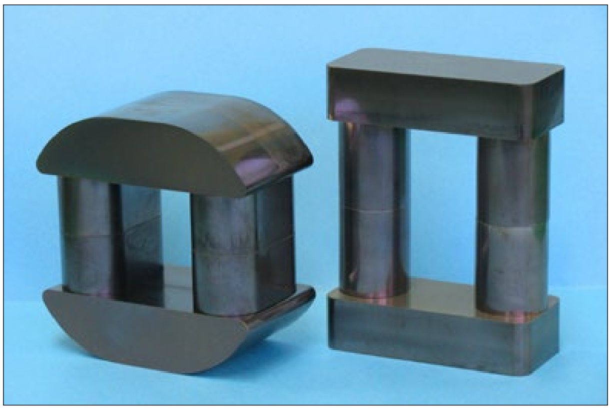

Fig. 6 SMC reactor core (Courtesy JPMA)

In this new material a dispersion of hard particles was adopted to increase wear resistance. Cr-type hard particles were selected based on both their effect on wear resistance and their cost. Machinability is an important factor as the inner diameter is machined during the engine manufacturing process. Because machinability is generally reduced through the addition of hard particles, dispersion of a soft phase (Cu-phase) in the matrix was also used to improve the machinability.

It has been confirmed that the new material offers 50% less wear than the company's conventional material without machinability deterioration.

Net shape reactor core with a newly developed insulating lubricant

Hitachi Chemicals Co. Ltd received a further award for a pure iron Soft Magnetic Composite (SMC) reactor core (Fig. 6) for a Photovoltaic device which is used for voltage boosting and rectification inside the inverter.

The hardness of pure iron SMC itself is low and therefore, in the compaction process, pure iron powders tend to undergo plastic flow, leading to destruction of the insulation films. In this condition, the original magnetic characteristics are unavailable because of a drastic increase in eddy current loss. The company therefore developed a new lubricant for SMC which can prevent the plastic flow from a sliding surface as well as improving the insulation properties.

A pure iron SMC core (Fe: 99%, others ≦ 1%) was used, with the powders particles being coated with insulation films comprising both inorganic and organic elements. In order to achieve high density and strength, the die-wall lubrication method was used. One of the lubricant elements slides between metal powders and the die, protecting the metal particle shape and preventing plastic flow, whereas, one of insulation elements combines with insulation films preferentially and improves the insulation properties of the sliding surface.

Equivalent specific resistivity values were achieved for the sliding surface and compaction surface and low core losses were also maintained. Manufacture of the net-shape reactor core was achieved with the developed lubricant without surface finishing.

Fig. 7 Synchroniser hub for a dual clutch transmission used for automotive transmissions (Courtesy JPMA)

Development prize: Process

Development of a DCT synchroniser hub through laser quenching technology

Sumitomo Electric Industries (SEI) received a process development prize for the production of a synchroniser hub for a Dual Clutch Transmission (DCT). The synchroniser hub (Fig. 7) is used in a newly developed 7-8 speed DCT, where the required tolerance of the inner spline diameter is very exacting compared with other hubs.

The Fe-Cr alloy material developed by SEI required an optimised sintering process in order to achieve superior hardenability. A laser quenching operation was applied to achieve local, selective hardening.

The dimensional accuracy after the sintering process has been improved by using the Fe-Cr alloy and by reducing the sintering time to only one third of that normally used with an Fe-Ni alloy. By controlling sintering conditions, such as cooling rate, a fully bainitic structure could be produced and this enabled deformation during the sizing process. The laser quenching concentrated energy on the surface, generating a very shallow quenching layer with a hardened depth of around 0.5 mm, therefore reducing thermal influences on the product dimensions.

As a result, dimensional change was reduced by half compared with induction hardening and the required accuracy was achieved. A further benefit of laser quenching is its ability to achieve the required cooling rate without coolants or oil, due to the shallow quenching layer

New powders prize

A Ni-free alloyed steel powder providing a tensile strength of 600MPa and excellent machinability

JFE Steel Corporation received a new powder development prize for a mixed powder without a nickel addition that is applied to iron based sintered parts and is superior in terms of strength and machinability (Fig. 8).

Conventional iron based sintered parts with a tensile strength of 600 MPa are made from a 4% Ni alloyed steel powder that is alloyed by diffusion bonding of the alloying elements (Ni, Cu, Mo). The problems with this alloy are high cost, poor machinability and the supply restrictions for nickel. These issues have led to the development of a Ni-free alloyed mixed powder, which is lower in cost and provides the required tensile strength of 600 MPa and excellent machinability of sintered parts.

In this development, the tensile strength of 600 MPa is achieved by using a lean Mo pre-alloy (0.45 mass% Mo pre-alloy) and producing a homogeneous metallographic structure by liquid phase sintering. A high density compact is obtained by reducing the added amount of a lubricant especially developed for high density compaction. Furthermore, the uniformity of hardness distribution resulting from the use of a pre-alloy powder improves the machinability. The results of this have led to a large reduction of cost for raw materials and machining processes and have been rated highly by several sintered parts suppliers.

Development prize: Equipment

Integrated production line for shock absorber parts

Fine Sinter Co. Ltd received a prize for the development of an integrated production line (Fig. 9) used for manufacturing a wide variety of shock absorber parts.

The aim was to establish a system where parts can be shipped three days after the start of compaction. As low volume parts accounted for almost 40% of the total parts produced, the system concept had to work for all volumes. A production line, integrating the steps from compaction to the sizing process and ensuring a six second cycle time, 500 pieces lot size and one minute set up time, was the goal.

Fine Sinter developed down sized presses and tool sets which enabled one minute set up for both the compaction and sizing processes. A reduction of sintering time to just one third of that conventionally achieved has been delivered successfully by reviewing the heat zones. In addition, to prevent defects such as cracks, industrial robots have been arranged to perform a centralised control of the parts flow from the compaction to the sizing process.

As a result, Fine Sinter successfully developed an integrated production line with a lead time from compaction to sizing within 44 minutes, including the setup time for the tool sets. The downsizing of the compaction to sizing process line to 70% in length and 60% in installation space could be achieved.

In 2010, one production line based on this concept was established in Japan and began manufacture. Since then, two further lines based on the concept have been installed in overseas plants.

Effort prize

Sintered oil-less bearing for a valve switching motor for high-temperature operation

Porite Corporation received an effort prize for the development of a sintered oil-less bearing (Fig. 10) for a valve switching motor. Used in a vehicle electronic throttle system or exhaust gas recirculation system, the sintered bearing replaces a ball bearing.

The bearing has to operate in high-temperatures (180°C to 200°C), as well as have load bearing and vibration resistance characteristics. The existing Cu-Sn material was replaced by an Fe-Cu-Sn material and, by incorporating a solid lubricant, gave the characteristics to support lubrication in the use in which oil film formation was difficult.

As a result, wear and vibration resistance were much improved and the ball bearing at the output side of the valve switching motor could be successfully replaced with a sintered bearing.

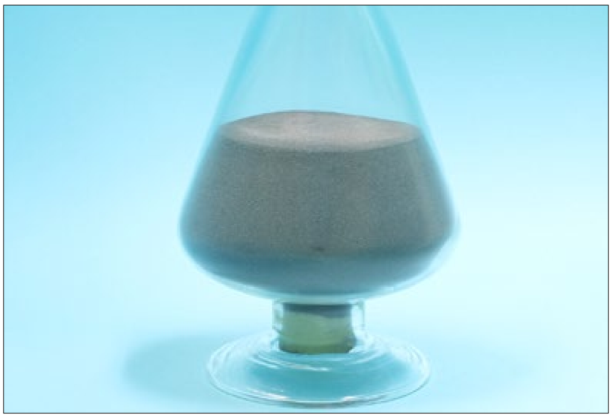

Fig. 8 A Ni-Free Alloyed Steel Powder, providing a tensile Strength of 600MPa (Courtesy JPMA)

Fig. 9 Integrated production line exclusively for shock absorber parts (Courtesy JPMA)

Fig. 10 Sintered oil-less bearing for a valve switching motor for high-temperature operation (Courtesy JPMA)

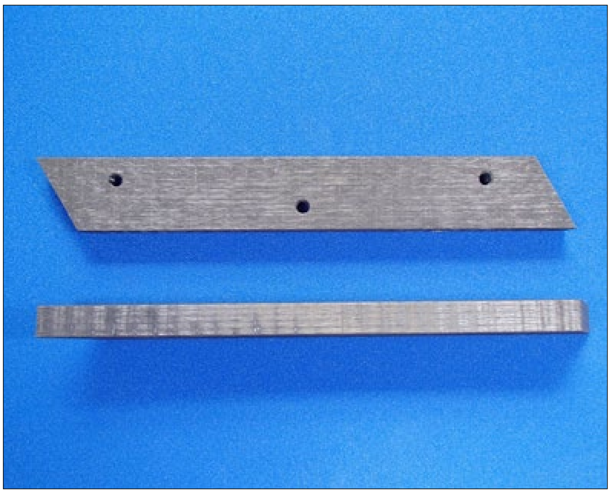

Fig. 11 Sintered contact strip to be attached to pantographs of trains (Courtesy JPMA)

Sintered contact strip material, made of carbon fibre reinforced carbon composite impregnated with copper alloy for use on train

Fine Sinter Co. Ltd received an award for the development of a sintered contact strip to be attached to pantographs of trains (Fig. 11).

Carbon contact strips (composite of graphite and copper or copper alloy), which contribute to the extension of contact wire life, are often adopted in preference to the conventional sintered copper alloy contact strips. Because carbon contact strips use carbon powder as a base material, there have been cases of failure during use, due to brittleness. Moreover, a steel sheet sheath has had to be installed on the contact strip for reinforcement before fixing it onto a pantograph. An improvement to this system was desired.

In this project, a high strength Carbon fibre reinforced Carbon composite (C/C) contact strip was developed by making a composite of copper alloy through a Powder Metallurgy process. In this manufacturing method, the C/C is overlaid with impregnation material made of powdered copper and powdered titanium as a base, formulated only in the amount required for impregnation, and atmospheric impregnation is performed inside a continuous sintering furnace. To enable atmospheric impregnation, wettability was increased by improving the formulation and the spaces between the woven fabrics were used as impregnation paths.

By using high strength C/C composite as a base material, an approximate doubling of the strength of current carbon contact strips has been achieved, resulting in reduced failures during use, and a significant decrease in contact wire wear which contributed to an extension of the contact strip replacement cycle. Thanks to the increased strength, the strip can now be directly threaded and no longer requires reinforcement by a sheath for fixing.

Fig. 12 Miniature tool set, manufactured by MIM (Courtesy JPMA)

Miniature Tool Set

Castem Co. Ltd received an award for a miniature tool set, manufactured by Metal Injection Moulding (MIM) (Fig. 12). There have been many miniature tools, for example for key chains or accessories, but most of these have limited functionality being made from materials such as silver, die-cast aluminium or zinc.

The use of MIM has enabled these tools to be made with complicated three-dimensional moveable parts out of real tool materials, such as stainless steel and tool steel. The set includes 11 miniature tools: Micrometer, Scissors, Needle Nose Pliers, Hacksaw, Water Pump Pliers, Wire Cutters, Machine Vice, Callipers, Adjustable Wrench, Pliers and C Clamp.

Product development for the miniature tool set has been carried out by the company's experienced engineers who have carefully designed the moulds for the tools. The materials used for the micrometer and callipers are SUS630, equivalent to 17-4. SKD11, equivalent to D2 Tool Steel, was selected for all the other tools.

www.jpma.gr.jp

PM INDUSTRY EVENTS

2015

STPMF2015
April 8-10, Nancy, France
www.stpmf2015.fr

PM China 2015 Expo
April 27-29, Shanghai, China
www.cn-pmexpo.com/en

PowderMet2015 - International Conference on
Powder Metallurgy & Particulate Materials
May 17–20, San Diego, CA, USA
www.mpif.org

AMPM Additive Manufacturing with Powder Metallurgy
(co-located with PowderMet2015)
May 17–19, San Diego, CA, USA
www.mpif.org

Rapid 2015
May 19-21, Long Beach, California, USA
www.rapid3devent.com

PM Titanium 2015
August 31 - September 3, Lüneburg, Germany
www.hzg.de/pmti2015

Euro PM2015
October 4-7, Reims, France
www.epma.com

Ceramitec 2015
October 20-23, Munich, Germany
www.ceramitec.de

APMA 2015 3rd International Conference on Powder Metallurgy in Asia
November 8-10. Kyoto, Japan
www.apma.asia

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