VOL. 4 NO. 2 SUMMER 2015

POWDER METALLURGY REVIEW

PM AUTOMOTIVE COMPONENTS

AUTOMATED HANDLING SYSTEMS

INDIA'S DYNAMIC PM INDUSTRY

ipmd.net

Published by Inovar Communications Ltd

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

Subscriptions

Powder Metallurgy Review is published on a quarterly basis. It is available as a free electronic publication or as a paid print subscription. The annual subscription charge is £85.00 including shipping.

Advertising opportunities

Contact Jon Craxford, Advertising Director, to discuss how we can help promote your products and brand, both online and in print.

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

Design and production

Inovar Communications Ltd.

ISSN 2050-9693 (Print edition)
ISSN 2050-9707 (Online edition)

POWDER METALLURGY REVIEW

PM: The first choice for structural parts production

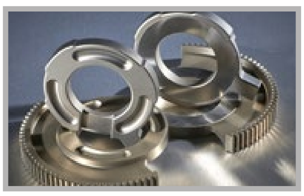
Powder Metallurgy offers many advantages to end-users looking to reduce manufacturing costs, improve mechanical properties and incorporate a range of unique characteristics into their components. The automotive industry has for many decades recognised this potential and is the largest consumer of PM structural components, with numerous PM products proven to meet the high demands that this sector expects. In this issue of *PM Review* we present an extensive 19 page report outlining the factors driving the PM automotive structural parts industry forward (page 35).

The automation of part handling through all stages of production can prevent costly failures and lead to improved quality and increased productivity. Lutz Lackner, Dorst Technologies GmbH, outlines a number of options available when considering such systems (page 55).

India's rapidly growing manufacturing and engineering sectors offer many opportunities for the PM industry. Each year the Powder Metallurgy Association of India organises its international conference and exhibition to provide a forum for both national and international PM professionals to meet and discuss their latest innovations. Prof Ramamohan Tallapragada provides an overview of this unique event (page 63).

Also from India is a new post-sintering gas alloying process developed to improve the mechanical properties of low alloy PM parts. Fluidtherm Technology's Pownite process involves a controlled nitrogen diffusion in the metal matrix of parts and our review on page 75 outlines the process and provides examples of its application.

Paul Whittaker
Editor, *Powder Metallurgy Review*



Cover image
This ball ramp actuator, comprising of a sector gear and fixed ring, is made for Magna Powertrain by Cloyes Gear & Products, Inc.,USA. The actuator applies torque to the front wheels in BMW's X-Drive transfer case (Courtesy MPIF)

POWDER METALLURGY REVIEW


31


47


56


72


79

in this issue

regular features

industry news

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

Makin Metal Powders expands production capacity

Makin Metal Powders Ltd, based in the UK and one of the largest European producers of copper and copper alloy powders, has announced a £500,000 investment in new atomising equipment at its Rochdale facility. Supported in the investment by Chinese parent company GRIPM, the newly installed and commissioned equipment will provide a significant increase in its production capacity.

Makin's Managing Director John Boden stated that the investment shows the confidence that the company has in both the global demand for its products and the long term future of the Rochdale operation. An opportunity to provide new employment in the area, the new plant is already in full operation, ensuring Makin has the ability to react to increasing demand.

Makin manufactures copper powder, bronze powder, tin powder, infiltrants and press-ready pre-mix powders along with other related alloys from its purpose built 10,000 m^2 production facility. The company utilises both water and air atomising systems with sieving, sintering and alloying capability.

The production processes and systems are accredited to both ISO 9001 and ISO 14001 and all are REACH compliant.

www.makin-metals.com

SHW AG raises €24.6 million for major capacity expansion

SHW AG, a leading supplier of automotive pumps, engine components and brake discs, has announced that it has raised approximately €24.6 million through the issue of new ordinary bearer shares.

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.

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. The company generated group sales in fiscal year 2014 of €430 million.

www.shw.de


MPH 500
SACMI

Alcoa to buy titanium supplier RTI International Metals for $1.5 billion

Alcoa has announced the signing of a definitive agreement to acquire RTI International Metals, Inc., a global supplier of titanium and specialty metal products and services for the commercial aerospace, defence, energy and medical device markets. Alcoa will purchase RTI in a stock-for-stock transaction with an enterprise value of $1.5 billion.

"Alcoa is accelerating its value-add growth engine by acquiring titanium leader RTI," stated Klaus Kleinfeld, Alcoa Chairman and Chief Executive Officer. "We are combining two innovators in materials science and process technology, shifting Alcoa's transformation into a higher gear. RTI expands our aerospace portfolio market reach and positions us to capture future growth to deliver compelling value for customers, shareholders and employees."

RTI will expand Alcoa's advanced manufacturing and materials technologies. Its high-velocity machining, forming, extruding and parts assembly operations will enable Alcoa to produce some of the largest, most complex aerospace components. Advanced titanium Powder Metallurgy and processing technology will enable cost-effective production of near net shape aerospace components, as well as medical devices and oil and gas products. The purchase will also expand Alcoa's Additive Manufacturing capabilities to produce titanium, specialty metals and plastic parts for aerospace, medical and energy applications.

"Innovation and scale are critical to winning in both the titanium and aerospace industries today, which is why this transaction is such a natural strategic fit for both RTI and Alcoa," added Dawne Hickton, Vice Chair, President and Chief Executive Officer of RTI International Metals. "We are pleased to have an agreement with Alcoa that delivers immediate value to our shareholders that appropriately reflects the strength of our business. Through this combination of forces, RTI will take its innovative technologies to the next level and deliver even more value-add titanium solutions to meet customer needs. We look forward to continuing to accelerate RTI's success as a part of the Alcoa team."

www.alcoa.com
www.rtiintl.com

Höganäs to acquire Abril Industrial Waxes

Sweden's Höganäs AB has announced that on June 1, 2015, it will acquire 100% of the lubricants manufacturer Abril Industrial Waxes Ltd, based in Wales, UK. Höganäs acquired 19% of Abril in 2010 and is using its option to acquire the remaining shares in the company.

"This is a strategic acquisition as it allows Höganäs to enhance its expertise in lubricants and further develop its offering of sophisticated metal powder mixes," stated Melker Jernberg, President and CEO of Höganäs.

Höganäs stated it plans additional investment in the company to further develop Abril's business, namely waxes and lubricants for industrial purposes and consumer goods. Production will remain in Pyle, Wales.

"With Höganäs' long-standing industrial experience, Abril's products and ability to develop new materials and formulae will be in safe hands," stated Bernard Cooke, owner and CEO.

Abril Industrial Waxes Ltd was founded in 1945 and today the company employs around 20 people.

www.hoganas.com

Ames Laboratory scientists create new lower cost magnetic alloy

Karl A Gschneidner and fellow scientists at the US Department of Energy's Ames Laboratory, Iowa, USA, have created a new magnetic alloy that is an alternative to traditional rare-earth permanent magnets. The new alloy, a potential replacement for high-performance permanent magnets found in automobile engines and wind turbines, eliminates the use of one of the scarcest and costliest rare earth elements, dysprosium, and instead uses cerium, the most abundant rare earth.

The result, an alloy of neodymium, iron and boron co-doped with cerium and cobalt, is a less expensive material with properties that are competitive with traditional sintered magnets containing dysprosium. Experiments performed at Ames Laboratory by post-doctoral researcher Arjun Pathak and Mahmud Khan (now at Miami University) demonstrated that the cerium-containing alloy's intrinsic coercivity - the ability of a magnetic material to resist demagnetisation - far exceeds that of dysprosium-containing magnets at high temperatures. The materials are at least 20 to 40% cheaper than the dysprosium-containing magnets.

"This is quite exciting result. We found that this material works better than anything out there at temperatures above 150°C," stated Gschneidner. "It's an important consideration for high-temperature applications."

Previous attempts to use cerium in rare-earth magnets failed because it reduces the Curie temperature, the temperature above which an alloy loses its permanent magnet properties. The research team discovered, however, that co-doping with cobalt allowed them to substitute cerium for dysprosium without losing desired magnetic properties.

www.ameslab.gov

New president at Höganäs Brasil

Adriano Machado has been appointed President of Höganäs Brasil Ltda and Head of Region South America for the metal powder producer. He began the role on 1 April, 2015, following the departure of Claudinei Reche.

Machado has been with Höganäs Brasil for five years working in the sales and supply chain. For the past three years he has been Commercial Director. He has a degree in Foreign Trade, an MBA from FGV in Brazil and an Executive Certificate in Innovation and Strategy from MIT Sloan.

"Adriano is a valued member of the management team for Region South America," stated Melker Jernberg, Höganäs President and CEO. "With his experience he is well suited to take over the positive development started and managed by Claudinei Reche."

www.hoganas.com

Ford to invest $2.5 billion in new engine and transmission plants in Mexico

Ford has announced that it is investing $2.5 billion USD in new engine and transmission plants in Mexico. The investment will see a new engine plant in Chihuahua, expansion of Ford's I-4 and diesel engine lines in Chihuahua and a new transmission plant in Guanajuato, Ford's first transmission plant in Mexico.

The car maker stated that its investment, which comes during the celebration of Ford's 90th anniversary in Mexico, will bring 3,800 new jobs plus additional indirect jobs to the country.

"Ford is making a significant commitment to our business in Mexico with investment in two new facilities, while aiming to make our vehicles even more fuel-efficient with a new generation of engines and transmissions our team in Mexico will build," stated Joe Hinrichs, Ford's President of The Americas. The new engine facility is being built within Ford's Chihuahua Engine Plant. This $1.1 billion investment will allow Ford to export engines to the USA, Canada, South America and the Asia-Pacific region, supporting the company's small car lineup.

An additional $200 million investment is tied to the expansion of Ford's current I-4 and diesel engines production in Chihuahua. As a result, the Ford Engine Plant in Chihuahua will become the largest engine plant in Mexico.

In addition, Ford is building a new transmission plant within the premises of transmission supplier and long-time partner Getrag, based in Irapuato, Guanajuato. This $1.2 billion investment brings approximately 2,000 new jobs.

www.ford.com

Metaldyne recognised by General Motors as a 2014 Supplier of the Year

Metaldyne LLC, headquartered in Plymouth, Michigan, USA, was presented with a GM Supplier of the Year award during the auto maker's 23rd annual Supplier of the Year awards ceremony on March 5th in Detroit. The company was recognised in the Powertrain category for its design, engineering and supply of connecting rods, which are provided to GM in a number of global markets.

GM's Supplier of the Year awards were presented to 78 suppliers worldwide, less than 1% of its supply base, who have consistently exceeded GM's expectations and created outstanding value. This is Metaldyne's second consecutive year to receive the award from GM.

"These companies are the best-of-the-best suppliers, and deserving of special recognition for their outstanding contributions," stated Steve Kiefer, GM Vice President, Global Purchasing and Supply Chain. "We need them to continue to bring us their most innovative technologies and highest quality services and work and we will continue to win together for the benefit of our customers."

The Supplier of the Year award winners are chosen by a global team of GM purchasing, engineering, quality, manufacturing and logistics executives. "Being recognised as a General Motors' Supplier of the Year for two consecutive years is an exciting acknowledgement for all Metaldyne employees," stated Thomas Amato, President and CEO, Metaldyne LLC, and Co-President of Metaldyne Performance Group.

"All of us at Metaldyne strive to provide General Motors and all our customers unrivalled support and leading technology and we will continue delivering the best possible products and services to our customers well into the future."

Metaldyne manufactures a range of Powder Forged con rods

The award was accepted on behalf of Metaldyne and its employees by Thomas Amato and George Lanni, Metaldyne's Vice President of Sales – Sintered Products.

www.metaldyne.com

HC Starck reports increased sales despite weak market development

The HC Starck Group, headquartered in Munich, Germany, has reported that in 2014 the company increased its sales volume to €785.9 million, up from €703.9 million in 2013.

"The increase in sales was also supported by our strategic growth projects in Asia: the tungsten joint ventures in China and Vietnam. That helped us grow significantly our tungsten powder business, and gain large market shares especially in Asia," stated Andreas Meier, CEO of HC Starck. "Overall, though, 2014 was shaped by the difficult economic situation in our global core markets, which hurt the profitability of the business."

Sales in the tungsten powder division increased by more than €75 million in 2014, bolstered by new customers and market share gains. In addition, the tungsten joint venture in China led to a significant sales-volume increase. The tungsten component business also saw a clear increase in sales volume, in particular thanks to the competitive cost structure at the division's Chinese manufacturing site.

In the tantalum and niobium powder business, HC Starck reported no increase in demand. But despite this difficult market environment, the company was able to gain market shares for tantalum powders and reinforce its competitive position.

In the Surface Technology and Ceramic Powders division, H.C. Starck saw a double-digit percentage increase in sales. In particular, the thermal spray powder business benefited from increased demand in the United States and several new products and customers. The products sold under the names Amperit and Ampersint are important materials for energy production, medical technology as well as the oil and gas industry.

Despite the difficult situation in 2014, H.C. Starck managed to increase its investments up to around €40 million. The major part of the budget was spent for the construction of the production facilities of the new tungsten joint venture in Vietnam, into the German production sites and into the further expansion of the tungsten joint venture in China.

Research and development focused on projects to increase the yield in processing secondary materials and by-products, to continuously improve the quality of high-capacity tantalum and niobium powders, and to develop special tungsten carbides for the Asian market. Additionally, HC Starck signed a development contract with Rapid Prototype and Manufacturing, a US company specialising in Additive Manufacturing.

www.hcstarck.com

CVMR announces move to USA and creation of Centre of Excellence for Innovation in Powder Metallurgy

CVMR Corporation, a manufacturer of high-purity metal powders and superalloys, is moving its operations from Toronto, Canada, to Oak Ridge, Tennessee, USA. The company also announced the creation of the CVMR Centre of Excellence for Innovation in Powder Metallurgy and production facilities. The move will see an investment of $313 million and is expected to create some 620 jobs.

The CVMR Centre of Excellence for Innovation in Powder Metallurgy will collaborate with academic, industrial, government and businesses entities interested in the development of advanced materials and innovative technologies. The centre will focus on production of new metallurgical products that can benefit the metal industry.

CVMR, which has operations in 18 countries, will use the former Theragenics building at Horizon Center in west Oak Ridge for its headquarters, research and development. It was stated that the company could expand this 65,000 ft^2 building as infrastructure already in place allows it to be doubled.

Kamran M Khozan, CVMR Chairman and CEO, stated that the Oak Ridge facility will be at the centre of the entire company. "We are in 18 different countries," Khozan said. "The head office will be right here in this building. I promise to make Oak Ridge the centre for innovation and manufacturing."

The company plans to begin operating by the end of May 2015 and will transfer to Oak Ridge the production of advanced metal materials for a variety of industries, including aerospace, energy, automotive and medical devices. CVMR plans to quadruple its production capacity at the site over the next three years and will begin construction of additional facility in June 2015. "We expect to be much bigger and invest much more in the next five years," Khozan added.

The Oak Ridge facility will house CVMR USA's corporate headquarters, research and development, production of nanomaterials and metallurgical coating services, customer support, product development and planning for US production facilities, according to the release.

Ores concentrated overseas in locations such as the Philippines, Indonesia and African countries will be shipped or sent by barge to Oak Ridge, where they will be processed. CVMR uses the ore concentrates to create pure metal powders. The company works with 52 metal powders and metal concentrates including nickel, iron and cobalt.

www.cvmr.ca

Linde sets up Combustion Centre in Suzhou, China

The Linde Group has opened a facility in Suzhou, China, for the development of new combustion and heat treatment applications in the Asia Pacific region. The Linde Combustion Centre will work in partnership with metal and glass industries and research institutes on projects to develop green combustion technologies and improve heat treatment processes.

The centre incorporates cutting-edge technology to enable research and development work in metallurgy, steel, iron, nonferrous, mining and heat treatment industries. It also has an R&D demonstration facility for customers, allowing for closer interaction when designing solutions specific to their needs.

"China, together with the Asia Pacific countries, is a key growth region for The Linde Group. At the speed of development in this region, industries will increasingly seek for advanced solutions that are sustainable with greater emphasis on process efficiencies and product quality. This is the trend we are seeing especially in China," stated Steven Fang, The Linde Group, Regional Business Unit Head, East Asia.

Linde states that the setup in the Suzhou Centre can demonstrate to potential customers the best operational practice of safe gas supply and robust application techniques in the heat treatment field, especially for carburising, sintering and cryogenic processes.

Linde has three existing R&D centres in the US, Europe and China supporting the application activities in those regions. The three centres will collaborate in global and local R&D initiatives, through the sharing of technology, training and capability building in applications technology development.

www.linde.com

Management changes at Bosch Mahle Turbo Systems

Bosch Mahle Turbo Systems, a joint venture between Bosch and MAHLE with headquarters in Stuttgart, Germany, has announced that Dr Roger Busch and Alexander Kutsch will be replacing the company's previous Managing Directors, Dr Martin Knopf and Dr Andreas Prang.

Dr Busch has been appointed Managing Director, Development, Sales, Finances and IT at Bosch Mahle Turbo Systems and has taken over from Dr Knopf who left the company on January 31, 2015. Roger Busch has many years of experience within the Bosch Group.

Bosch Mahle Turbo Systems currently employs approximately 700 people with locations in Stuttgart and Blaichach in Germany, St. Michael in Austria and Shanghai in China.

www.bmturbosystems.com

European funding for Powder Metallurgy processes in nuclear reactor components

The UK's Nuclear Advanced Manufacturing Research Centre (AMRC) is leading a new European research project to develop advanced Powder Metallurgy techniques for applications in the civil nuclear industry. Over the next 18 months the PowderWay project will investigate processes to create high-integrity reactor components from metal powder.

The project will investigate how techniques such as Hot Isostatic Pressing (HIP), Additive Manufacturing and Spark Plasma Sintering can be used to create high-integrity, near-net shape parts from metal powder, avoiding the need to machine parts down from solid billets. A number of these methods are already used in industries such as aerospace, but are not yet qualified and approved for civil nuclear applications.

The Nuclear AMRC will manage the industry-led project to assess the potential for these processes in the civil nuclear sector and establish a strategy to move the most promising techniques into commercial production. Other partners in the €360,000 project include AREVA, EDF's research laboratory, French nuclear suppliers group PNB, the French energy commission CEA and Swedish materials research group Swerea. PowderWay is funded by the Nugenia nuclear industry association, with support from the European Commission's framework programme for collaborative R&D.

The Nuclear AMRC is also involved in another new EU-funded project, MMTech, to develop Additive Manufacturing techniques for an advanced alloy, gamma titanium aluminide. This project is led by the University of Sheffield AMRC and funded by the European Commission's Horizon 2020 programme.

www.namrc.co.uk

Mincon acquires Marshalls Hard Metals

Ireland's Mincon Group has acquired UK based tungsten carbide manufacturer Marshalls Hard Metals Limited. The business and assets have been transferred to a new company, Marshalls Carbide Limited, which is a 100% owned subsidiary of the Mincon Group. Financial terms of the transaction have not been disclosed.

Marshalls Hard Metals, based in Sheffield, UK, is one of Europe's leading tungsten carbide specialist manufacturers supplying the oil and gas, construction and mining, aerospace and engineering industries. In the 12 month period to the end of December 2014, it is reported that the business had revenues of approximately £4.25 million, of which sales to Mincon accounted for approximately 20%.

www.mincon.com | www.hardmet.com

New deburring system from Abtex for green Powder Metallurgy parts

Abtex Corporation of Dresden, New York, USA, has announced a new machine for deburring Powder Metallurgy parts in the green state. Green parts, those that have been pressed but not yet sintered, are much less expensive to deburr than the same parts after they are hardened in the sintering process, stated Abtex.

The new machine uses brushes in an innovative configuration that deburrs opposite sides of a part in a single pass, accounting for further savings. The machine/brush interface is specially designed to remove only the dangerous burrs, preserving each part's unique geometry. Brushes can be easily customised for the specific deburring task.

The machine is also made for easy and efficient interface with existing equipment in any powdered metal manufacturing environment. It is built for 24/7 use and designed to communicate both upstream and down. It features a chassis that can be raised and lowered by up to 25 cm (10 inches) to provide an efficient interface with existing equipment.

www.abtex.com

The GP-2 deburring system for green PM parts

MPIF announces Distinguished Service to Powder Metallurgy Award winners

The MPIF Awards Committee has announced the recipients of its 2015 MPIF Distinguished Service to Powder Metallurgy Award. The award recognises individuals who have actively served the North American Powder Metallurgy industry for at least 25 years and, in the minds of their peers, deserve special recognition.

The 2015 Award Recipients were named as François Chagnon, Robert J Dowding, Ulf Engström, Howard A Kuhn, Thomas J Miller, César Molins, Jr., James H Neill, Craig C Paullin, Thomas W Pelletiers, Dennis Poor, Prasan Samal, Blaine Stebick, S K Tam and John von Arx.

www.mpif.org

ELNIK takes *the gamble* out of buying MIM debind and sinter equipment with the help of DSH Technologies!

Elnik provides **FREE TRIAL RUNS BEFORE YOU PURCHASE OUR EQUIPMENT** to prove how cost-efficient our technology can be

Wasted MIM production runs resulting in “half-baked” parts can cost you thousands $$! Unless you rely on **Elnik Systems.** We are the only MIM debind and sinter manufacturer who offers you free test runs using full sized production equipment at **DSH Technologies,** our own MIM laboratory. What’s more, **DSH** provides comprehensive metallurgical assistance and turnkey production solutions that will help you avoid countless pitfalls which can arise unexpectedly in the MIM parts manufacturing process.

THESE SERVICES INCLUDE:

Try Before You Buy Elnik offers 2 free trial runs on DSH Production furnaces*

R&D Work DSH Partners with existing or new potential customers involved with processing MIM parts of any material for industries including Medical, Aerospace, Lifestyle, Military and Automotive.

Toll Debind and Sinter Services
DSH provides the option to rent its Equipment by lot of contract for short term requirements or the occasional over capacity run

Consulting DSH also partners with companies who want to establish turnkey solutions for all aspects of the MIM parts producing process

(*Elnik Systems will charge for 2 trial runs on DSH production equipment. Should a furnace be purchased within 1 year of these trial runs, Elnik will provide full credit for 2 trial runs off the price of the purchased equipment.)

ELNIK SYSTEMS
Innovation. Experience. Excellence.

DSH TECHNOLOGIES,LLC

107 Commerce Road | Cedar Grove, NJ 07009 USA | +1.973.239.6066 | www.elnik.com

Large tungsten carbide blank produced by Spark Plasma Sintering

Spain's Nanomaterials and Nanotechnology Research Center (CINN) has fabricated what it claims is the first 400 mm pure tungsten carbide blank produced by a hybrid Spark Plasma Sintering-Hot Press (SPS-HP) process. The sintering technique utilises a combination of both induction and joule heating.

The production of the tungsten carbide blank at the facilities of the Multifunctional Materials Development Unit marks an important milestone in the development of the Spark Plasma Sintering (SPS) technology. The achievement demonstrates the possibility for industrial scale fabrication of large components via the SPS-HP process.

The Nanomaterials and Nanotechnology Research Center (CINN) is a joint research centre established in 2007 by an institutional initiative of the Spanish Council for Scientific Research (CSIC), the Government of the Principality of Asturias and the University of Oviedo. These three institutions contribute to the CINN with funding as well as scientific facilities and staff.

The CINN combines a high-quality and internationally competitive interdisciplinary research with scientific and technological demonstration activities and has among its objectives the creation of new technology-based companies.

www.cinn.es

Mark Saline appointed General Manager of Sinterite and C.I. Hayes

Mark Saline has been appointed General Manager of US based Sinterite and C.I. Hayes, the furnace manufacturing companies within the Gasbarre Furnace Group. Saline brings almost 30 years of technical and business experience in the Powder Metallurgy industry to the group.

Sinterite, located in St. Marys, Pennsylvania, designs, manufactures and services custom continuous belt and batch furnaces for sintering, steam treating, annealing, brazing and heat treating applications.

Located in Cranston, Rhode Island, C. I. Hayes offers a full line of vacuum and atmosphere furnaces.

www.sinterite.com

Keep in shape when the heat is on

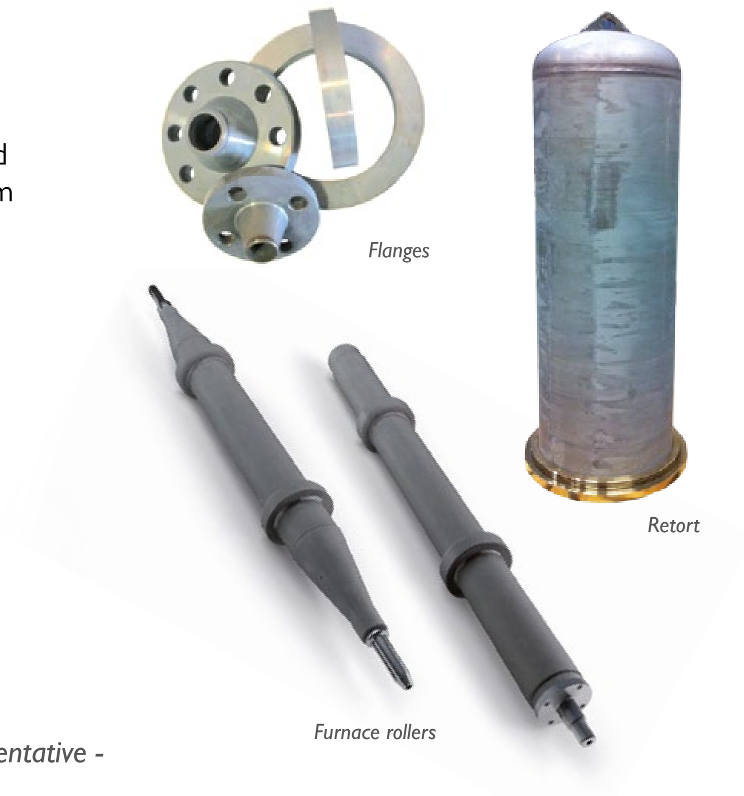
Kanthal APMT™ for strength and corrosion resistance at extreme temperatures

KANTHAL

Heat treatment at 1250°C (2282°F)

We offer the complete material and heating solution

- Advanced powder metallurgical FeCrAlMo super alloy for service in the temperature range 800 to 1300°C (1470 to 2370°F)
- Combines excellent resistance to oxidation and hot corrosion with high creep resistance / form stability
- Outstanding resistance to sulphur and carburizing environments
- Unique combination of strength and corrosion resistance at extreme temperatures
- Applicable for structural parts like nozzles, flanges, furnace rollers and retorts in a wide range of high temperature processes
- More energy efficient in high-temperature processes than conventional materials



Flanges

Retort

Furnace rollers

Want to know more? Contact your local sales representative - or visit www.kanthal.com

SANDVIK

New binderless nano-polycrystalline diamond tool for milling cemented carbide

There is increasing demand for ever higher precision moulds, dies and punches made from cemented carbide. They are used, for example, in the production of small and intricate optical components. Such moulds and dies are often made from extremely tough ultra-fine grained WC-Co cemented carbides which are very difficult to machine to shape and to a mirror finish. Even conventional polycrystalline diamond (PCD) tools are often insufficient in chipping resistance, wear resistance and edge sharpness.

Sumitomo Electric Industries Ltd (SEI) in Japan has addressed this challenge by developing a nano-polycrystalline diamond (NPD) tool designated 'Sumidia Binderless NPD10' which is harder than even single polycrystalline diamond and which is capable of machining tough cemented carbide with higher precision and for a longer period.

A report published in Sumitomo Industries Technical Review (No. 79, October 2014, pp 86-90) states that the NPD10 nano-polycrystalline, single-phase diamond uses graphite as the starting material. The graphite is converted into extra-fine diamond particles (30-50 nm) at ultra-high pressure (15 GPa or higher) and high temperature (2200°C or higher), with the particles directly bonded together without using any binder. Each nano particle in the NPD tool is a single crystalline diamond oriented in a different direction. Because NPD10 diamond is non-conductive and cannot be machined into the desired shapes using EDM, SEI has developed a special machining technique to produce shapes such as the ball-nose end mills used for the direct milling of higher-precision cemented carbide moulds/dies (Fig.1).

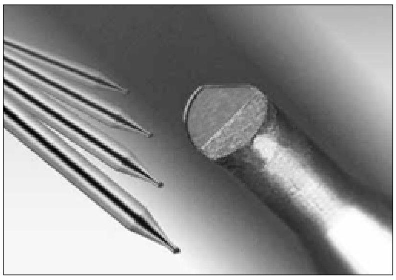


Fig. 1 Sumidia ball-nose endmills made from binderless nano-polycrystalline diamond

The report states that NPD10 showed good cutting performance, even under conditions where single crystalline diamond may chip off, and was found to be far superior in wear resistance to coarse-grained PCD (Fig. 2). In addition, the NPD10 diamond tool made by directly bonding nano-sized particles together has high grain boundary strength and can maintain edge

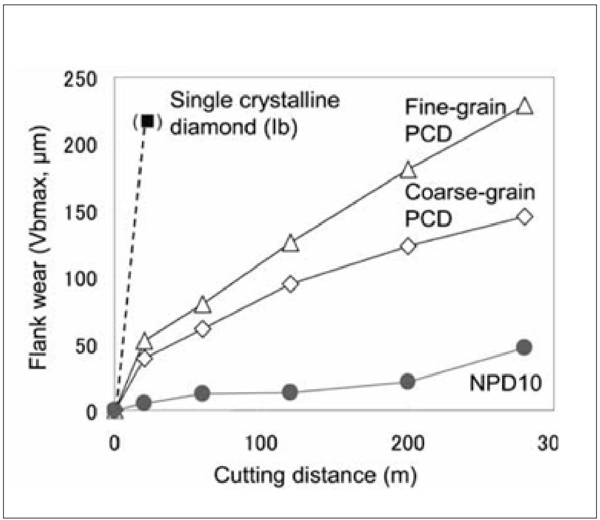


Fig. 2 Comparison of various diamond materials used for machining cemented carbides

sharpness to produce mirror finishes on the cemented carbide. However, it may be realistic to first carry out rough-machining with an electroplated grinding wheel or similar before carrying out the semi-finishing and finish machining with the NPDB endmill.

www.global-sei.com

Powder Technology course to run at Lund University

A three day course on Powder Technology in Pharma, Food, Chemistry and Metallurgy is scheduled to take place at Sweden's Lund University, September 9-11, 2015. The aim of the course is to provide participants with a better understanding of powder products and processes and to supply tools to stimulate new ideas for development and improvement of powder products and processes.

The course format includes round table discussions focusing on specific themes such as rheology, powder characterisation, granulation, agglomeration and processing of metal powders.

The first two days of the course will focus on particle properties and physical behaviour, properties of powder and particle size enlargement. The third day allows participants to choose between the either powder processing or metallic powders and their applications.

The metallic powders and their applications programme discusses methods for producing metal powders, microstructure control and powder preparation. Shaping and consolidation, including sintering, HIP and full density processing, is covered along with the characterisation of powder products and material properties.

www.luvit.ced.lu.se


© 2015 DEMAT GmbH
Photo: Alexander Meier / Image rights: MB Tech
Product Range
Additive Manufacturing & 3D Printing
Moldmaking and Tooling & Production
Design & Engineering
euromold.
World Fair for Mold- and Patternmaking, Tooling, Design, Additive Manufacturing and Product Development
From Idea to Series Production
Become an exhibitor
Innovation meets Investment.
September 22 – 25, 2015
Düsseldorf, Exhibition Centre
Book your stand now: www.euromold.com

Atomising plant waste material finds new use

Sweden's Höganäs AB has reported that Petrit E, a product made from residual material generated by its atomising plant in Halmstad, is now used in the production of stone wool. Sales volumes are expected to double during the coming year, states the metal powder producer. The furnace generates around 13,000 tonnes of slag each year. Expectations are that most of it will be sold as Petrit E for stone wool production.

Petrit E contains some iron oxide which makes it well suited for the production of stone wool as it makes the wool more resistant to fire. "Last year we delivered around 5,000 tonnes of Petrit E for mineral wool production," stated Björn Haase, Manager Non Metal Products. "We believe we will be able to double that number this year. For Höganäs the benefits of Petrit E are several; there is a sales revenue and we also save money by not having to dispose of the slag. We are one step closer to our vision of generating Zero Waste."

www.hoganas.com

Petrit E is made from slag from the arc furnace in Halmstad, Sweden.

New website launched by Japan Powder Metallurgy Association

The Japan Powder Metallurgy Association (JPMA) has launched an updated version of its website. The newly designed site features both Japanese and English language versions and provides information about the association and its activities. Listed on the website are member companies along with news, information about JPMA award winners and a selection of industry statistics.

www.jpma.gr.jp/en

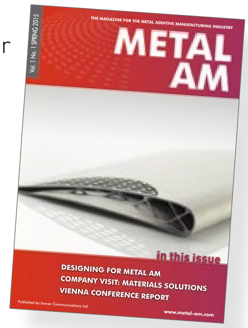
Launch issue of *Metal Additive Manufacturing* magazine now available to download

The launch issue of *Metal Additive Manufacturing*, the new quarterly magazine for the metal Additive Manufacturing industry, is now available to download from the publication's dedicated website, www.metal-am.com.

Available in both print (ISSN 2057-3014) and digital (ISSN 2055-7183) formats, *Metal Additive Manufacturing* brings 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.

The 64 page launch issue includes a report on a recent visit to leading European metal AM parts producer Materials Solutions, based in Worcester, UK. Materials Solutions is a key supplier to the aerospace and high performance motorsport industries. In our exclusive report the company's founder and Managing Director, Carl Brancher, shares his thoughts on the current status of the metal Additive Manufacturing industry and the opportunities and challenges ahead.

Also featured in this issue is an extensive report on component design considerations for powder bed fusion technologies. As Tim Richter, RSC Engineering GmbH, Germany, explains, this technology has the potential to fundamentally change the design process and appearance of new products. Designers must, however, be aware of all design considerations to maximise the potential of their products.



Jon Craxford, Sales Director at Inovar Communications, a publishing house with over twelve years of experience in the metal powder processing industries, commented, "We are delighted with the support that we have received from industry suppliers, component manufacturers, trade organisations and international industry events."

The print edition of *Metal Additive Manufacturing* is available by subscription. The launch issue is also being distributed at AMPM 2015 (May 18-20, San Diego, USA), RAPID 2015 (May 18-21, Long Beach, USA), and the Rapid.Tech exhibition (June 10-11, Erfurt, Germany).

www.metal-am.com

New materials and sinter hardening route for PM synchroniser hubs

Synchroniser hubs produced by Powder Metallurgy are extensively used in manual and dual clutch automotive transmissions, and their success stems from PM's ability to provide the combination of high strength and wear resistance during gear changing. As can be seen in Fig. 1, the synchroniser hub has inside and outside splines and they are usually formed having external teeth, a rim and a boss each with different thicknesses. The outer diameter also has three notches. The high strength is needed to withstand the transmission torque and high hardness to withstand the sliding with the sleeve which mates with the external teeth.

Nickel containing sintered steels have traditionally been used to provide the desired properties for synchroniser hub applications but due to cost and availability factors there have been moves recently to reduce the PM industry's dependency on nickel as an alloying element. Additionally, using Ni-containing steels requires a long sintering time at high temperature and a post sintering hardening step is required to achieve the desired high strength and hardness. Researchers at Sumitomo Electric Industries (SEI) have been investigating the development of new types of chromium-containing PM steels as a replacement for Ni-steels and Yu Akiyama and his colleagues at SEI's Product Development Department recently reported on the success of these new Cr-based steels in *SEI Technical Review* [1]. They state that chromium has hardenability equal to or greater than nickel, and also because the diffusion rate of Cr-containing PM steels is higher, overall sintering time can be reduced.

The authors found that whereas Ni-based alloys require a rapid cooling of >50°C or more per second to obtain a complete martensitic phase, Cr-based alloys can transform to a complete martensitic phase even with a low cooling rate of 2°C or more per second. This slower cooling rate can be incorporated into the high temperature sintering cycle, eliminating the need for a post-sintering hardening step. The new 'HM-120' grade is produced by this slow cooling route to achieve an homogeneous bainite structure. The other two grades 'DM-80SH' and 'HM-120SH' are cooled more rapidly after sintering by injection an inert cooling gas to obtain a fully martensitic structure. DM-80SH is sintered at a conventional temperature of 1100-1200°C whereas HM-120SH is sintered at >1200°C.

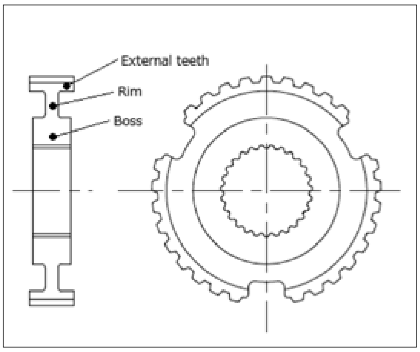


Fig.1 Sintered synchroniser hub used in manual and dual clutch automotive transmissions [1]

In combination with the use of sinter-hardening technology for

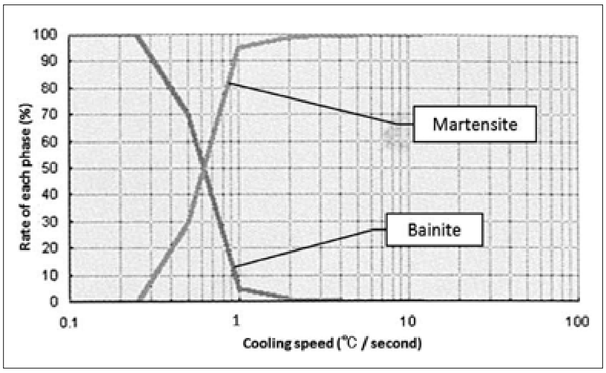


Fig. 2 Cooling speed and rate of each phase in Cr-based PM steel materials [1]

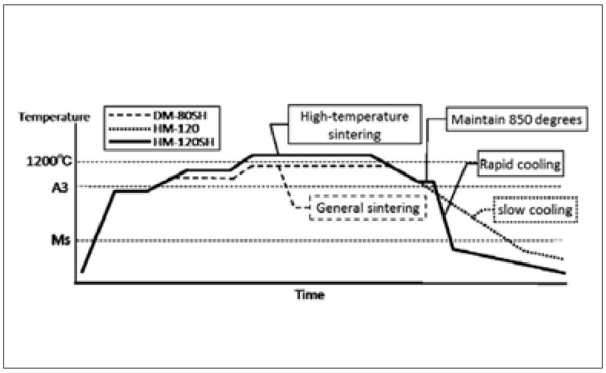


Fig. 3 Sintering cycles for each of the Cr-based alloys [1]

Cr-based PM steel alloys used for synchroniser hubs, SEI reports that it has also developed a new type of roller-hearth high temperature sintering furnace. The furnace uses a shutter between each temperature zone – degassing, preheating, sintering, slow cooling, rapid cooling chamber and cooling chambers. This is said to improve temperature distribution and temperature control compared with conventional sintering furnaces and reduces dimensional variations in the sintered parts. For example, 'HM-120SH' grade produced by rapid cooling sinter hardening has dimensional distortion half of that of conventional grade 'H-110' which is carburised in oil at 50-80°C/sec. The researchers state that this is because the significant differences in the cooling speed in carburising in oil can easily cause dimensional distortions. This is avoided in the sinter hardening of Cr-based steel products.

The researchers at SEI state that the rapid cooling chamber of the new furnace is unique to the PM industry and is capable of a cooling rate of 3-5°C/sec. The furnace has the capability to switch from rapid cooling to slow cooling by controlling the speed of the gas fans in the rapid cooling chambers and the speed of the rollers transporting the parts through the furnace. Fig. 3 shows the sintering cycle of each of the developed Cr-based alloys.

Reference

[1] Y. Akiyama, etal. *Sumitomo Electric Technical Review*, No 79, October 2014, 91-95

www.global-sei.com

Solid Oxide Fuel Cell innovations on display at Hannover Fair

Convion Ltd, Fraunhofer IKTS and Plansee SE presented their latest developments in Solid Oxide Fuel Cell (SOFC) technology and products at this year's Hannover Fair, Germany, April 13-17, 2015. Between them the companies displayed a range of interconnects through to ready-to-install stacks and complete SOFC systems.

Convion C50 SOFC system

In February 2015 Convion Ltd, based in Finland, began operation of a new, highly innovative co-generation system using MK351 stacks produced by Fraunhofer IKTS. "The Convion C50 SOFC system can be operated with natural gas or biogas. It has nominal power output of 58 kW with 53% electrical efficiency and over 85% total energy efficiency," stated Erkko Fontell, CEO of Convion.

Depending on the fuel gas the company states that there are low or no CO_2 emissions. The C50 is suited for either outdoor or indoor installations and does not require water connection. Operation parallel to the grid or in an island mode secures critical loads in case of power outages.

As modular units, C50 power modules can be installed in a parallel configuration facilitating installations with higher power output. The manufacturing of the product has been successfully finalised and the validation with 20 kW net power has been started. Convion currently seeks to commercialise the new product and to bring it to the market with interested partners and to showcase the future of distributed power generation.

MK351 stacks from Fraunhofer IKTS

The MK351 stack design was jointly developed by Fraunhofer IKTS and Plansee. It consists of only a few component parts and allows for a simple and automated assembly. All stack components withstand high temperatures, system and temperature cycles. A perfect matching of components to each other allows the desired high power density of the cell and the required cycle stability.

Currently, the performance degradation of a stack integrated in a hot box is < 0.7 %/1000 h. "This value was confirmed by several experiments including long-term test with over 18,000 hours of operation," stated Dr Mihails Kusnezoff, Head of Department Materials and Components at Fraunhofer IKTS.

Fraunhofer IKTS and Plansee offer a licence of latest background technology and IP for the MK351 stack design, so that interested companies will be able to start commercial production of such stacks.

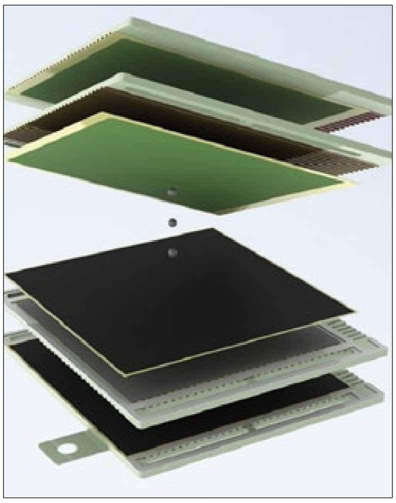
CFY interconnects from Plansee

CFY is a chromium-base alloy containing 5% iron by weight as well as traces of yttrium. The physical properties of the CFY alloy make it ideal for use in high-temperature fuel cells. The coefficient of thermal expansion is adapted to match that of the high-performance electrolyte based on fully-stabilised zirconium oxide, for example 10ScSZ or 8YSZ.

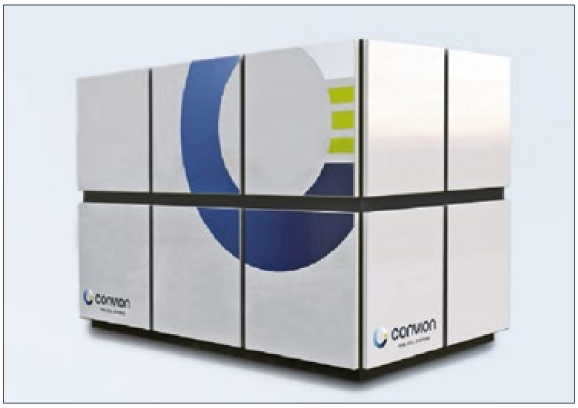
"Plansee CFY interconnects are based on a scalable, cost-effective powder-metallurgical net-shape production, which significantly reduces production costs through a high degree of automation and high material yields," stated Prof Dr Lorenz Sigl, Head of Innovation Services at Plansee.

Beside MK351 interconnects, Plansee produces several CFY interconnect designs for customers worldwide in pilot and industrial lines.

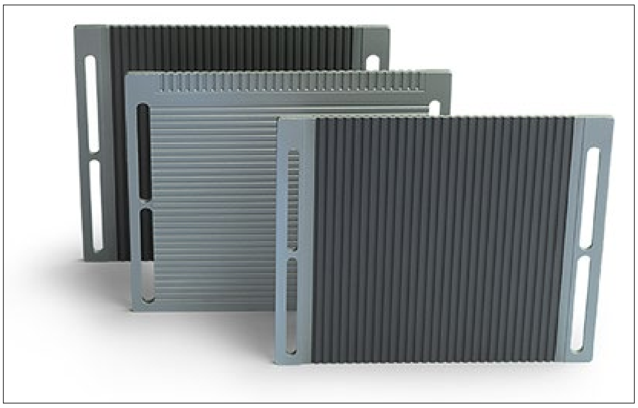
www.convion.fi
www.ikts.fraunhofer.de
www.plansee.com



The MK351 stack design was jointly developed by Fraunhofer IKTS and Plansee



The Convion C50 SOFC system has nominal power output of 58 kW with over 85% total energy efficiency



Plansee CFY interconnects are based on a scalable, cost-effective powder-metallurgical net-shape production

New EPMA hardmetals Club Project to focus on micro-mechanical testing

The European Powder Metallurgy Association (EPMA), through its European Hardmetals Group, (EHMG) is launching a new club project on micro-mechanical testing: a quantitative method for measuring local mechanical properties in hardmetals. The project is in partnership with CEIT San Sebastian, NPL London and UPC Barcelona.

The proposed project is an exploratory study to assess the ability of microsample testing to measure mechanical properties of hardmetals at the local scale. This includes the behaviour of individual features such as WC grains, WC-WC interfaces and the binder. For this purpose microsamples of different geometries (beams, pillars) will be machined using FIB and tested with a nanoindenter system to measure force–displacement information.

This project is the first stage of what could be an ambitious programme aimed at the development of robust metrology for the mechanical characterisation of key microstructural features in hardmetals.

The research will be partially co-funded by NPL so the overall cost to the project partners will be €27.12k, to be shared by the participants (minimum of four). The project is planned to start in the next few months and will run for eight months. It is open to all EPMA Members.

For more information contact Dr. Olivier Coube, EPMA Technical Director, oc@epma.com

www.epma.com/projects

International Porous and Powder Materials Symposium

The 2015 International Porous and Powder Materials Symposium and Exhibition (PPM 2015) will be held in Izmir, Turkey, from September 15-18, 2015. The organisers state that the symposium is expected to be one of the largest gatherings of its kind with a broad attendance from academia, research organisations and industry.

The symposium will also host an exhibition for displaying products, characterisation equipment and production technology, as well as parallel workshop sessions for those who would like to introduce their process, procedures and equipment. The official language of the symposium is English.

www.ppm2015.org

Innovation drives Powder Metallurgy structural components forward in the automotive industry

The Powder Metallurgy process offers a number of distinct advantages over other metal working technologies. It allows companies to reduce manufacturing costs, improve properties and incorporate a range of unique characteristics into components used in a wide range of applications. There have been a number of factors driving developments in the ferrous PM structural parts sector over recent years. Dr David Whittaker reviews the advances in both materials and processing technology that make PM the first choice for structural parts production.

Through advances in both materials research and processing technology, Powder Metallurgy continues to find new applications in a wide range of industries. The automotive sector is one of these industries and is an established market for PM, accounting for around 80% of all ferrous structural PM components produced. By providing solutions to the challenges of this evolving sector, PM is not only chosen to manufacture new automotive component designs but also used to replace existing structural parts manufactured by other processes (Fig. 1).

Recent advances in materials and process technologies for the manufacture of PM structural parts have been based on a number of key drivers. These include the option for increased strength and performance, enhancing dimensional control capability, reducing product costs and responding to the requirements of health and safety legislation.

With increased strength and higher performance materials available, PM has much to offer demanding applications such as those found in automotive engines and transmissions. A series of studies in the late 1990s [1, 2] concluded that the potential in this market was at least three times its size at that time. Today, many appli-

Fig. 1 This actuator, comprising a sector gear and fixed ring, is made for Magna Powertrain by Cloyes Gear & Products, Inc.,USA. The actuator applies torque to the front wheels in BMW's high performance X-Drive transfer case and offers a 35% cost saving over the forged part it replaced (Courtesy MPIF)

Fig. 2 Added value can be generated by supplying assembled sub systems such as this planetary carrier assembly (Courtesy Keystone Powder Metal Company)

cations still exist that could benefit from PM technology. The manufacture of gears for automotive manual transmissions is one such application that continues to excite significant development activity. The key conclusions from recent work in this area are discussed later.

The ability to hold tight dimensional tolerances, and the consequent effect of removing the need for some finish machining operations, has been an important contributor to the cost competitiveness of PM products ever since the industry's first penetration of the structural parts market. Developments to enhance this capability even further are continuing to meet ever-increasing customer demands.

Providing a cost-effective manufacturing solution, in competition with other potential process routes, has been the bedrock of PM's penetration of the structural parts market. This continues to be the case, with the PM industry reacting well to factors that affect its costs such as the volatility of alloying element costs in recent times. Materials have been developed, for example, which remove, or substantially reduce, the use of these expensive elements.

Increased added value has been generated through the supply of assembled systems or sub-systems, rather than supplying individual PM parts. This has emerged as an important development trend and offers the customer a number of advantages (Fig. 2).

"Providing a cost-effective manufacturing solution has been the bedrock of PM's penetration of the structural parts market"

In common with other manufacturing technologies PM has been faced with the need to respond to increasing health and safety legislation. Specifically, concerns have been raised regarding PM workplace health hazards in the use of elemental nickel powders. The industry has been seeking technically viable alternatives to nickel as an alloying addition in PM mixes in order to reduce or even eliminate its use.

Materials development

Low alloy ferrous Powder Metallurgy materials are predominant in the press and sinter structural parts sector. These materials are generally based on water atomised or sponge iron powders with elemental alloying additions.

In common with wrought steels, a significant element in increasing strength is carbon, added as graphite. Copper is usually added for dimensional control purposes and to provide some solid solution strengthening. To enhance hardenability, the most commonly used additions have been nickel and molybdenum, as these elements do not form stable oxides at normal sintering temperatures.

Traditionally, more cost-effective hardenability agents such as chromium and manganese were not used because of the stability of their oxides at normal sintering temperatures. However, they can be used if high temperature sintering is employed and/or, increasingly, if the reducing capacity of the sintering atmosphere at normal temperatures can be increased by controlling dew point to low values.

A range of recent material developments have emerged, driven by one or more of the factors discussed in the introduction to this article. These developments are outlined in the following sub-sections.

Binder treated mixes

Developments of these alloying concepts have been driven mainly by the need to combine enhancements in both hardenability and dimensional control without detriment to achievable green density. For many years, the leading option for the achievement of these objectives was the diffusion alloying or partial pre-alloying concept first introduced in the mid-1970s.

These grades involve the use of a low temperature diffusion process to tack fine particles of alloying additions, generally Ni, Mo or Cu, to the base iron powder particles. However, it was recognised that additions such as graphite and lubricant could not be attached to the base iron powder particles by diffusion alloying and that these low-density additions are prone to dusting in powder handling and die-fill.

This has led to the development and increasing adoption of bonded pre-mixes, in which additions are held in place using an adhesive binder [3, 4]. Bonded pre-mixes were first introduced in the late 1980s and delivered, as expected, reduced dusting and segregation tendency for all additions and therefore improved consistency of sintering response and dimensional control. Improved and more consistent powder flow characteristics were also derived.

However, the original generation of bonded pre-mixes were seen as sacrificing some compressibility in exchange for these benefits. This was because the binder content was in addition to the normal pressing lubricant and therefore the total organic content, and therefore the volume fraction occupied by the organic constituents in the pressed part, was increased. This was overcome in the second generation of bonded pre-mixes, where alternative organic material additions were made, which were capable of acting both as binder and lubricant.

Grades are now available where all alloying additions are bonded to the base iron, as an alternative to diffusion alloying. These grades can show benefits over their diffusion alloyed counterparts in terms of higher apparent density and improved flow characteristics.

Hybrid alloy developments

Generally, the use of fully pre-alloyed powders in conventional press and sinter PM, whilst maximising the hardenability benefits of the alloying additions, has been seen as carrying the significant disadvantage of sacrificing compressibility and hence achievable green density, compared with the diffusion alloying and bonded pre-mix options.

However, during the past 15 years it has been recognised that certain alloying additions (particularly molybdenum) create little or no deterioration in compressibility in full pre-alloying. Consequently a number of molybdenum containing grades have been introduced into single press and sinter usage. Some of these grades, with up to around 1.5% Mo, have been specifically developed to make use of their superior hardenability in case hardening.

Hybrid powder grades, combining pre-alloying of the Mo addition and diffusion alloying or bonded ad-mixing of the other alloy additions, are now also available, with some of these grades containing lower pre-alloyed molybdenum contents. For instance, a recently developed material, Ancorsteel 30HP from Hoeganaes Corporation, contains only 0.3% pre-alloyed molybdenum, which, when combined with 2% admixed nickel, delivers adequate hardenability for compacts with small cross sections [5].

Leaner alloy developments

These developments have been driven by the needs for cost reduction and reduced or eliminated dependence on elemental nickel additions.

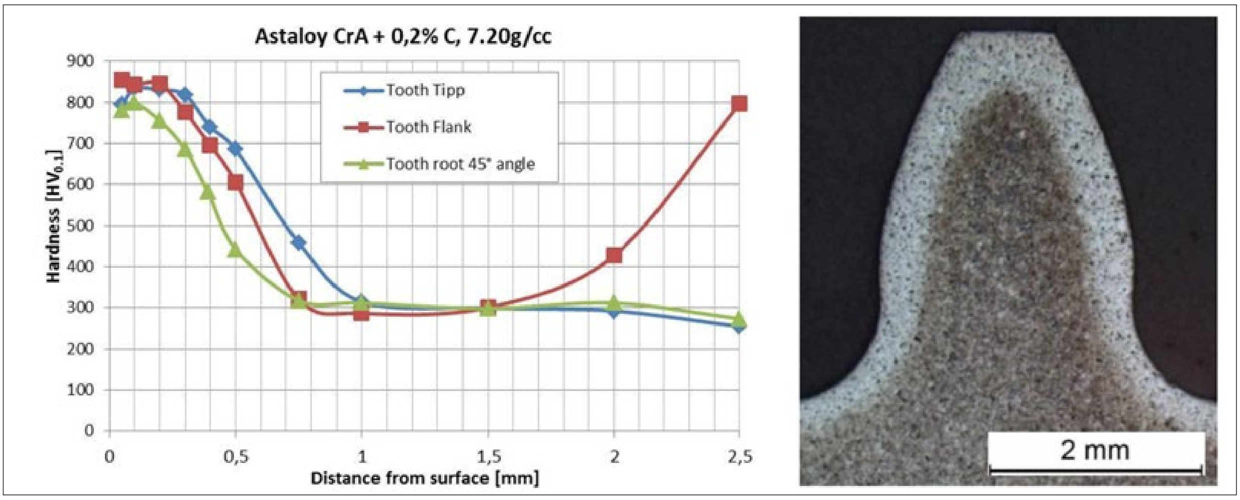


Fig. 3 Hardness profiles measured in three different locations of small spur gear (left) and overview of low pressure carburized case (right) (Courtesy Höganäs)

An early material development to find a viable alternative to the use of nickel as a hardenability agent came with the introduction by Höganäs AB of the 3%Cr-0.5%Mo Astaloy CrM grade in 1998 [6, 7], later followed by the leaner 1.5%Cr-0.2%Mo Astaloy CrL and 1.8%Cr Astaloy CrA. These materials were developed to offer equivalent mechanical properties to the nickel-containing diffusion-alloyed grades.

Höganäs has recently highlighted the potential benefits of using Low Pressure Carburising (LPC) and gas quenching to case harden Astaloy CrL and Astaloy CrA [8]. LPC is a boost-diffuse carburising process, in which the surface layers are saturated with carbon in short boost cycles followed by diffusion of carbon into the material under low pressure with a nitrogen back-fill. This enables the production of a well-defined case, not possible with conventional gas carburising of these materials, and hence potential benefits in terms of fatigue properties (Fig. 3). Höganäs also introduced a heat treatable, pre-alloyed Cr-Ni grade, Astaloy CMN (Fe-0.5Ni-0.5Cr-0.1Mo-0.2Mn) as a cost-effective replacement for Fe-Ni grades with higher nickel contents [9].

Hoeganaes Corporation has also launched a number of high strength grades with reduced nickel contents, for example Ancorsteel 4300, a binder treated Fe-1%Cr-1%Ni-0.8%Mo-0.6%Si [10, 11, 12], or with no nickel e.g. a binder treated Fe-0.9%Cr-1%Mn-1%Si-0.8%Mo using the AncorMax 200 binder/lubricant [13].

For grades that are designed to be heat treated by quenching and tempering, Hoeganaes Corporation has reported a trend towards the use of hybrid alloys, based on 1.5 wt% pre-alloyed Mo powder [14], but has also referred to recent work on a hybrid alloy with a pre-alloyed base with Mo content as low as 0.3 wt%. This latter material generated through-hardening in a compact of 13 mm diameter x 25 mm height and performance equivalent to higher Mo hybrid alloys and the fully pre-alloyed FL-4205.

Recent developments of lean Mn-Mo grades, with typical composition around Fe-1.3Mn-0.5Mo, have been discussed by both Hoeganaes Corporation [15] and Ames SA [16]. In the case of Ames, the Mn addition was made in the form of an Fe-Mn-C master-alloy.

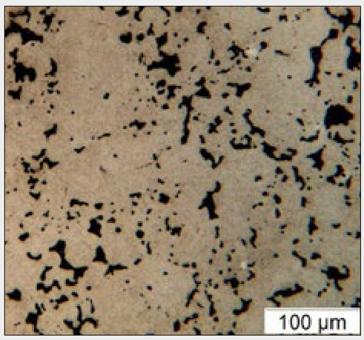
CASE STUDY 1

Lean alloy steel, Distaloy AQ, developed by Höganäs AB

An EPMA Excellence in Powder Metallurgy Award was presented to Höganäs AB of Sweden in 2010 for its development of the Distaloy AQ powder.

This powder was designed to have excellent machinability and sizing response in the sintered state with high strength and hardness after heat treatment.

Distaloy AQ contains only around 1% of alloying elements (nominal composition of 0.5%Ni and 0.5%Mo) and this helps to make the grade less sensitive to market price fluctuations. The development of Distaloy AQ was a good example of how customer needs were translated into solutions that benefit PM parts makers and their OEM customers, thus helping to improve the competitiveness of PM against alternative manufacturing technologies.



Microstructure of Distaloy AQ

Hoganas AB recently highlighted the use of Distaloy AQ, a diffusion alloyed grade containing 0.5wt% Ni and 0.5wt% Mo [17]. This material, on processing to a density level over 7.3 g/cm³ by warm compaction, can offer very high levels of dynamic properties, particularly after case hardening. Further information on Distaloy AQ is given in Case Study 1.

Rio Tinto Metal Powders discussed two developments aimed at offering leaner alloy variants. Firstly, it conducted design-of-experiment Taguchi studies, leading to the development of an expert system to select material formulation in order to achieve desired sets of properties (Table 1)[18]. These have led to the designation of leaner compositions to replace the standard diffusion alloyed Fe-Ni-Cu-Mo-C grades, FD-0405 and FD-0205. This work has shown that a steel, pre-alloyed with 0.85%Mo and with organically bound additions of 2.3%Ni, 1.15%Cu and 0.6% graphite, can deliver similar or even slightly better properties than FD-0405.

Mix #	Pre-alloyed Mo, %	Admixed Ni, %	Admixed Cu, %	Graphite, %	Cost index
1	0.0 (1001)	2.5	1.0	0.5	0.67
2	0.5 (4001)	2.5	1.25	0.6	0.77
3	0.85 (4401)	2.5	1.5	0.7	0.84
4	0.5 (4001)	3.0	1.5	0.5	0.85
5	0.85 (4401)	3.0	1.0	0.6	0.88
6	0.0 (1001)	3.0	1.25	0.7	0.76
7	0.85 (4401)	3.5	1.25	0.5	0.96
8	0.0 (1001)	3.5	1.5	0.6	0.84
9	0.5 (4001)	3.5	1.0	0.7	0.89
AVG	0.5	3.0	1.25	0.6	0.83
REF	1.25	4.0	1.5	0.6	1.00

Table 1 Description of mixes prepared (Taguchi L9). All mixes contain 0.6% EBS wax (Courtesy Rio Tinto Metal Powders)

Rio Tinto's second approach has been embodied in their novel development of the malleable iron powders concept [19, 20]. This concept has sought to mimic the malleabllisation of white cast irons. In the PM approach, an annealing heat treatment during powder production creates graphite precipitation around powder particle boundaries. A base material with a composition of Fe-2%C-1%Si was used to generate sintering densification through Supersolidus Liquid

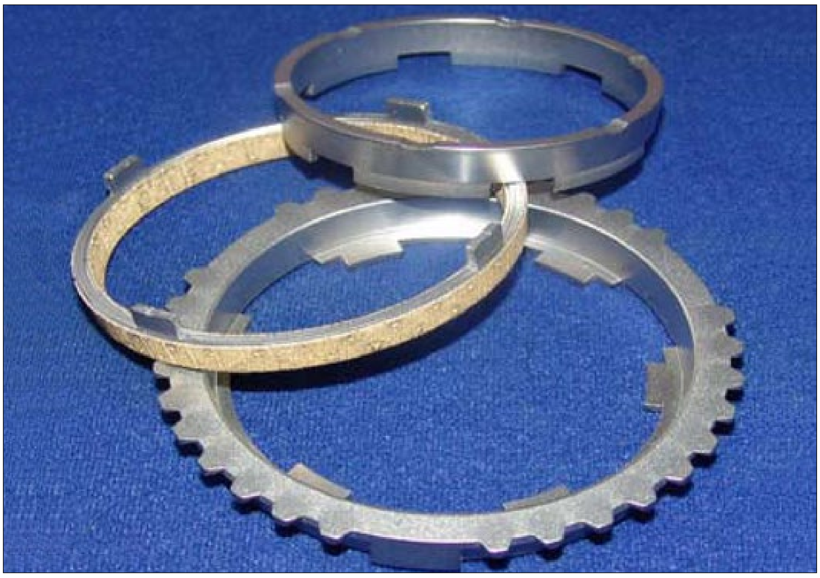


Fig. 4 High performance Fe-(1.5Mo-4Ni-2Cu) 0.6C grade PM synchroniser rings with carbon friction linings (Courtesy PMG)

Phase Sintering (SLPS) [19]. In a further refinement of this development [20], 0.2%P has been added to suppress the SLPS sintering temperature window to retain nodular graphite, rather than form flake graphite, and produce positive influences on achievable mechanical properties and particularly fatigue properties.

JFE Steel Corporation, Japan, has recently developed a new lean low alloy steel powder (pre-alloyed with 0.5%Cr, 0.2%Mn and 0.2%Mo and binder treated with 2%Cu), JIPS CRA, which won a 2014 Japan Powder Metallurgy Association (JPMA) prize. JIPS CRA has been demonstrated to offer equivalent as-sintered properties to those of the standard diffusion alloyed FD-0405 grade, with the exception of the Charpy impact strength, and heat treated properties that are also competitive with FD-0405 [21].

Use of master-alloy additions

The introduction of alloying elements through master-alloy additions has emerged as an enabler in the development of a number of the leaner, nickel-free grades, driven by the need for cost reduction.

However, master-alloy additions can also be used to promote the formation of a liquid phase and consequent densification during sintering. Krebsoge (now GKN Sinter Metals) was active in pioneering developments of this approach as long ago as the 1980s. Similar concepts have been adopted in the more recent developments by Stackpole International of their high density sintering materials [22, 23], which aim at a minimum sintered density of 7.75 g/cm^3 and by Ames SA [24].

"The introduction of alloying elements through master-alloy additions has emerged as an enabler in the development of a number of the leaner, nickel-free grades"

Developments in master-alloy additions at CEIT, San Sebastian, Spain, have received the prestigious Schunk Award at the Euro PM2005 Conference in Prague [25, 26]. The CEIT group has also collaborated with the University of Navarra in developing sinter-hardening grades based on the addition of Fe-Mn-C master-alloy and small amounts of Ni and graphite to Fe or Fe pre-alloyed with Cr and/or Mo [27].

Development of sinter-hardening material grades

As the efficiency of convective cooling systems in continuous sintering furnaces has been improved in recent years, sinter-hardening (i.e. a quenching treatment in the cooling zone directly after sintering followed by a tempering treatment) has emerged as a cost-effective alternative to a separate quenching and tempering heat treatment for the attainment of enhanced strength and performance.

As an aid to the introduction of the concept, powders with compositions specifically tailored for use in sinter-hardening have been introduced [28]. These materials are often hybrids involving full pre-alloying with elements such as Mo, Mn, Cr or Ni and diffusion-alloying or bonded mixing of additions such as Cu and sometimes Ni. The grades FLC-4608, FLC-4805, FLC-4808 and FLC-5305 have now been standardised by MPIF with other grades in the standardisation pipeline.

As the efficiency of convective cooling systems has been enhanced, leaner, more cost-effective sinter-hardening grades have been developed, notably Hoeganaes Corporation's Ancorsteel 721 SH (Fe-0.9Mo-0.5Ni-0.4Mn) [29] and Ancorsteel 4300L (Fe-1.0Cr-1.0Ni-0.3Mo-0.6Si-0.1Mn) [30, 31, 32] and Hoganas AB's Astaloy LH (Fe-0.9Mo-0.9Ni-0.25Mo) and Astaloy D-LH (Astaloy LH + 2% diffusion alloyed Cu) [33]. The benefits of using extra-fine nickel powder additions to enhance the sinter hardenability of hybrid diluted Fe-Cr-Mo steels have also been reported [34].

Work led by the groups at CEIT and University of Navarra, Spain, has also resulted in the development of a range of lean Fe-Cr-Mo-Ni-Mn-C sinter-hardening grades that utilise Fe-Mn-C master-alloy additions [35] or, as shown in collaboration with Pometon SpA, Italy, a proprietary lean pre-alloyed steel [36, 37, 38].

PMG has reported on its development of an Fe-(1.5Mo-4Ni-2Cu) 0.6C grade, specifically tailored for the sinter-hardening of high performance synchroniser rings (Fig. 4) [39].

Fig. 5 Powder forged automotive connecting rod produced by Metaldyne

Developments in the processing of PM components

Powder forging

The key process developments have been largely driven by the aim of increasing part performance, often by increasing achievable part density. Powder Forging (PF) is a long-established process, introduced at a time when press and sinter PM densities were limited to around 6.7 g/cm^3, but probably still offers the ultimate in capabilities for enhanced density and performance. This hybrid process involves preform production by conventional PM compaction/sintering followed by hot forging consolidation and delivers products with close to full density.

PF developments began in the late 1960s with the first serious market penetration arising in the mid-1970s. For a period, the market niche where PF offered a cost-effective option was mainly in large annular parts, because of the high material waste involved in competitive processes. Over the years, automatic transmissions have proved a particularly fruitful source of such applications, hence the more rapid take-up of the technology in the US market.

A further and very significant boost to market penetration arose

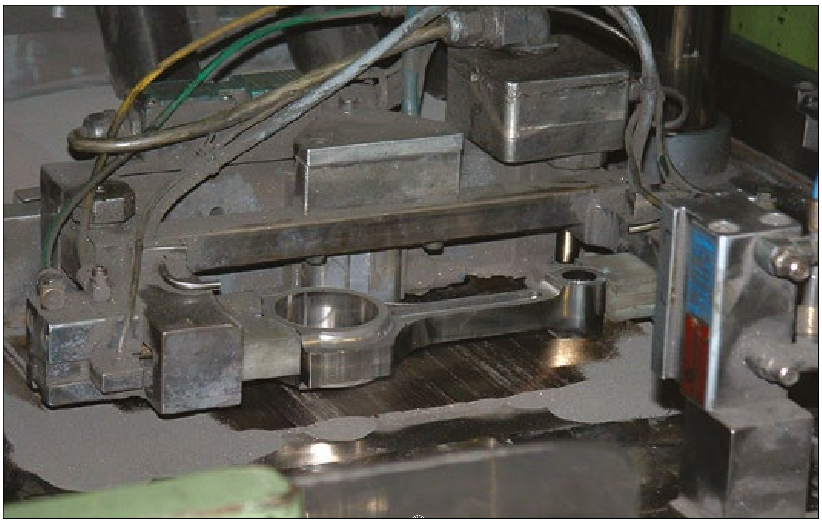


Fig. 6 Blended steel powders are compacted to produce near net shape con rod preforms for subsequent sintering and powder forging (Courtesy GKN Sinter Metals; photo Bernard Williams)

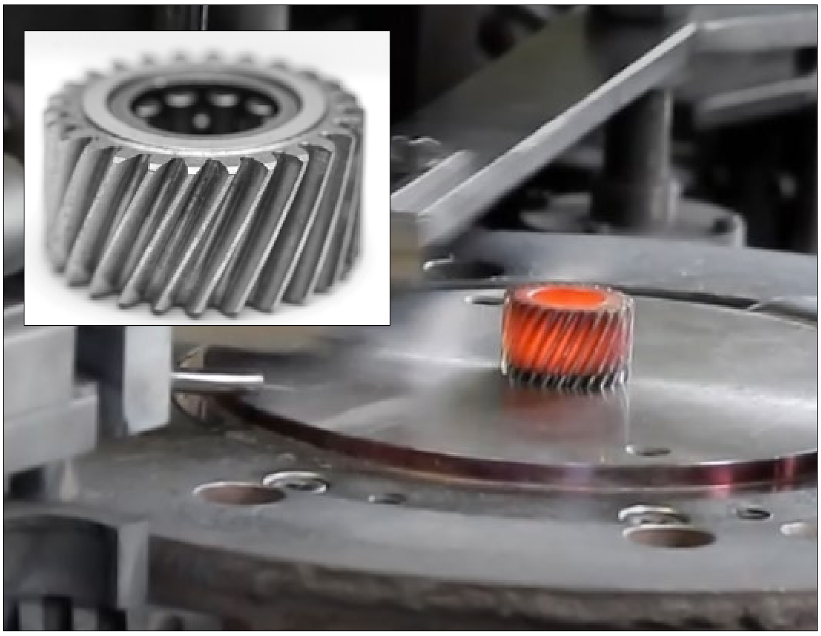


Fig. 7 This powder forged helical pinion gear from Keystone Powdered Metal Company marked a breakthrough for the PM industry (Courtesy Keystone Powdered Metal Company, USA)

with the adoption of the technology for connecting rod manufacture (Figs. 5 and 6). From an initial low volume application in Europe for the Porsche 928 engine in the mid-1970s, the technology was subsequently adopted, firstly in Japan by Toyota and then by the major US automotive producers, with Ford in particular later completing the full circle by introducing PF rods into European built engines.

The initial Porsche application had used fully pre-alloyed (and heat treatable) powder grades and this impacted on cost competitiveness compared with drop-forged steel rods, which were moving to the use of air-cooled, plain carbon steels. The subsequent developers of PF rods, therefore, moved to the use of Fe-Cu-C mixes, also used in the air-cooled condition.

PF conrods have proved to be a major success story for the PM industry, particularly in North America where they have captured over 60% of the total automotive conrod market, and it has been estimated that over one billion PF conrods have been produced world-wide to date.

During the course of the growth of the market penetration in the 1980s and 1990s, there were a number of suppliers of PF conrods. With the subsequent consolidation of the PM sector, PF conrod production is now controlled by just two groups, GKN Sinter Metals and Metaldyne Corporation, with the exception of Toyota's in-house operation.

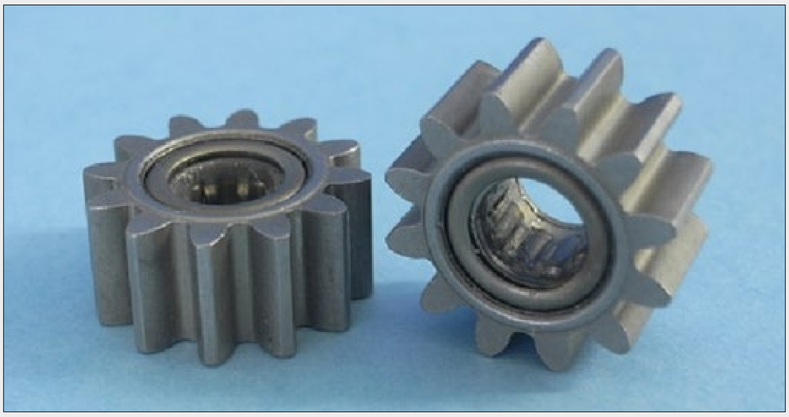
In recent years the drop forging industry has adopted a range of air-cooled connecting rod grades micro-alloyed with vanadium to increase strength (to respond to the automotive industry's move to engines with higher power densities) and to facilitate the introduction of fracture splitting of the big-end cap for cost saving. PF connecting rods had already demonstrated a capability for fracture splitting of caps [40, 41] and recent material developments [42, 43] have demonstrated that the tensile strength levels of the new high strength drop forged grades can be matched by the simple expedient of increasing copper level from the previous standard 2% to 3-3.5%, either admixed [42] or fully prealloyed [43].

It has further transpired, as reported in recent conference papers, that these material developments have introduced areas of additional competitive advantage for PF. Firstly, the high strength PF grades, while matching their drop forged counterparts in terms of tensile properties, have been demonstrated to offer superior fatigue strengths (a key design criterion), because of an observed lower scatter in fatigue properties [42].

Secondly and perhaps more unexpectedly, it has been shown that the high strength PF grades, while matching their drop forged counterparts in terms of room

CASE STUDY 2

High strength planetary gear for stop/start systems



Hitachi Chemical Co. Ltd. won a 2013 JPMA Powder Metallurgy Award for this planetary gear used in the starter motor of an idling stop/start system.

The increasing use of stop/start engine idling systems has resulted in the need for higher durability planetary gears in starter motors. High dimensional accuracy reduces stresses and Hitachi developed a sintered material for the planetary gear that provides high strength and high dimensional accuracy.

The density of the newly developed planetary gear was 7.4g/cm^3 after single pressing with the tool structure optimised for high pressure compacting. A high performance lubricant was used for improved ejection.

Sintering conditions were optimised to reduce deformation during sintering and to increase the amount of nickel rich austenite phase in order to obtain high plastic deformation during the sizing of the inner diameter. As a result, the dimensional accuracy of the newly developed material was improved by 60% and tensile strength was improved by 16% compared to the conventional 4% nickel material.

This planetary gear, which has high strength and high dimensional accuracy without quenching and machining, is already in mass production and contributing to cost savings, downsizing and weight reduction of the units.

temperature strength levels, actually show superiority in terms of strength at temperatures relevant to engine operating conditions (120-150°C) [44]. This unforeseen benefit has been attributed to secondary precipitation of fine copper-rich particles at these operating temperatures. This observation points towards a capability for reducing required safety factors in design and consequent light-weighting potential.

Outside the connecting rod field, the recent development by Keystone Powdered Metal Company, USA, of technology for the production of helical pinion gears for a planetary carrier assembly has been hailed as a significant breakthrough for Powder Forging [45] (Fig. 7). These parts are powder forged to full density using tools that must also rotate and exactly match the gears' 24.5 degree helix angle. This is the first time such a PF gear has been used in an automotive transmission application.

Higher pressure cold compaction
For complex, multilevel parts, involving tooling with thin section punches, the PM industry generally restricts compaction pressures to around 600 MPa or below. However, for some component geometries, it is feasible to increase forming pressures in conventional cold compaction.

Other potential applications for this approach were identified as synchroniser rings and cam lobes for assembled camshaft manufacture. As implied earlier, this approach has some geometrical restrictions, to more chunky, usually single-level parts. A further example of an application of high pressure cold compaction is described in Case Study 2.

"the production of helical pinion gears for a planetary carrier assembly has been hailed as a significant breakthrough for Powder Forging"

An award winning example of such an approach was the automotive starter gear developed by Sintertech S.A., France, in the late 1990s [46, 47]. This application involved compaction at 1050 MPa to produce a green density of 7.5 g/cm^3. Further densification in sintering and sizing (again at 1050 MPa) gave a final density of over 7.6 g/cm^3.

Warm compaction
In the mid-1990s a new variant on the compaction process known as warm compaction was introduced to the market by both Hoeganaes Corporation and Höganäs AB.

This process involves pre-heating both the powder and the forming tooling to around 130°C. This allows green density to be increased by

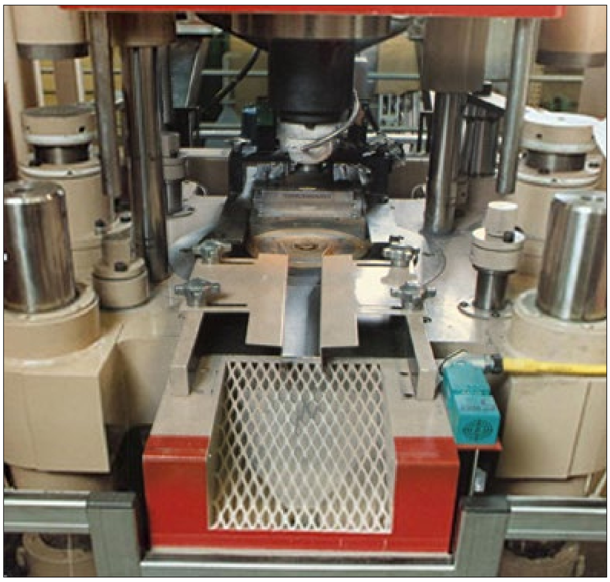


Fig. 8 Existing compacting presses can be retrofitted for warm compaction such as this 'El-Temp' system from Cincinnati Inc.

0.1-0.3 g/cm^3, compared with conventional cold compaction, resulting in improvements in mechanical properties by 10-20%.The higher green strength attained also makes it possible to machine parts in the green state.

Several systems for powder and tooling heating have been developed and are offered by a number of the leading press suppliers, often to be retro-fitted to existing presses (Fig. 8)[48]. Warm Compaction offers significant cost benefits over alternative approaches, such as Powder Forging, Double Press/Double Sinter and Copper Infiltration [49].

Several hundred component applications are now in production using this technology. Most of these are various types of helical gears for hand power tools, but automotive applications include sprockets, synchroniser rings and various hubs [50]. These automotive parts range in weight from 200 g to 1200 g. A warm compacted application is highlighted in Case Study 3.

Warm die compaction

This process is a variant on warm compaction, which has subsequently been introduced by Hoeganaes Corporation, based on the use of the binder-lubricant, AncorMax 200 [51] and, as it obviates the need for powder to be heated, is gaining greater popularity with PM parts makers.

The use of this binder-lubricant allows parts to be pressed to green density levels up to 7.4 g/cm^3, without heating the powder and with the tooling heated only to around 93°C (200°F) . This tooling temperature is only just above the level reached by frictional heating during conventional cold compaction, but the superior control over tooling temperature through thermostatic heating in this system contributes to the observed significant benefit in part weight consistency.

CASE STUDY 3

Warm compacted engine gears

Cloyes Gear and Products Inc. received a 2011 MPIF Award of Distinction in the automotive engine category for the intake sprocket gear and exhaust gear used in a coupling assembly in 2.0 and 2.2 litre diesel engines, made by General Motors Korea.

The gears receive torque from the timing chain, which drives the intake camshaft and transmits torque to the exhaust camshaft. The exhaust gear, also called a scissor gear, is an anti-backlash gear, which reduces backlash and mediates engine noise, vibration and harshness.

Warm compacted to a minimum density of 7.2g/cm^3 on the teeth, the PM steel gears have an ultimate tensile strength of 196,000 psi, typical yield strength of 161,000 psi, a fatigue limit of 55,000 psi and a hardness of 74 HRA after carburising. The gear teeth are shaved to achieve a tolerance of AGMA 9 rating.

PM's highly efficient material utilisation clearly demonstrates its sustainability benefits. The more traditional fabrication method for diesel engine parts, such as machined wrought steel gears, would have required an additional 8.6 pounds of material to be machined away.

The key to the higher density response is that this system employs specialised lubricants that allow a lower total amount of lubricant than in conventional systems (0.40 wt%). Because of this reduced lubricant content, however, the system is currently recommended only for part lengths below 32 mm.

A more recent lubricant development has been reported by Hoeganaes Corporation [52, 53], now designated as AncorMax 225. This lubricant allows warm die compaction temperatures to be increased to 107°C (225°F) and can be used with an addition level as low as 0.25 wt% to give green density levels approaching 7.5 g/cm^3 in high pressure warm die compaction and ejection characteristics equivalent to 0.75 wt%. Acrawax.

Collaborative work between Cloyes Gear, USA, and Hoeganaes Corporation [54] has led to the industrial scale verification of the use of the AncorMax 225 lubricant, at the 0.25wt% level, in warm die compaction. Trials have focussed on two valve train components (Fig. 9) and have assessed applicability to industrial mass production in terms of improvements in part weight control, density level and consistency of press tonnage requirements. This work has led to the conversion of these applications from warm compaction to warm die compaction.

Fig. 9 Main running gear, weight ~450 g (left); "Spro" gear, weight ~1100 g (right) (Courtesy Cloyes Gear, USA) [54]

Hoeganaes Corporation has also referred to lubricant developments for the warm compaction process that have allowed temperatures to be increased to 175°C [52].

Hoganas AB's lubricant Intralube E has also been shown to give very favourable response to warm die compaction and a recent paper [55] has indicated that a newly developed lubricant, X-Lube HD, may offer further improvements in lubrication ability with warm die compaction at die temperatures up to 90°C. The benefits of this new lubricant have been demonstrated in trials on a geometrically very demanding transmission gear application (Fig. 10).

"The most effective means of producing local densification in the surface layers of a PM part has been found to be the use of surface cold rolling"

Surface densification of sintered preforms

It is possible to increase density level in a PM product by applying an appropriate treatment after sintering. The most effective means of producing local densification in the surface layers of a PM part has been found to be the use of surface cold rolling.

Surface cold rolling was originally applied to improve rolling contact fatigue resistance of PM bearing races, but has subsequently been applied to the tooth profiles of both straight spur and helical gears to improve tooth bend fatigue strength and surface contact fatigue strength (pitting wear resistance), the early exponents of this approach being Hitachi Powdered Metals [56] and Stackpole International [57].

By rolling a pre-toothed PM preform, with a controlled amount of excess stock on the tooth profile, with a meshing toothed rolling tool, local densification can be created in the surface layers of the entire tooth profile (Fig. 11) [58]. With such a densified surface, the PM part can respond to a subsequent case carburising treatment in a similar way to a solid steel gear. By appropriate choice of PM material and initial core density level, equivalent performance to a machined and carburised AISI 8620 gear steel can be achieved in terms of both bend fatigue strength and surface fatigue strength [59].

Stackpole International has introduced a number of surface rolled gear applications into commercial production over the past decade or so (Fig. 12). A number of other PM groups [60, 61] have now also developed applications based on the use of surface densification by cold rolling (Fig. 13).

Sinter-hardening

The cooling zone in many modern sintering furnaces has been replaced by an integrated rapid cooling or gas quenching zone using water-jacketed cooling chambers with cooling rates up to 8°C/sec depending on the size of the parts, belt loading and belt speed. A tempering furnace can be connected to the gas quench unit. This results in a homogeneous

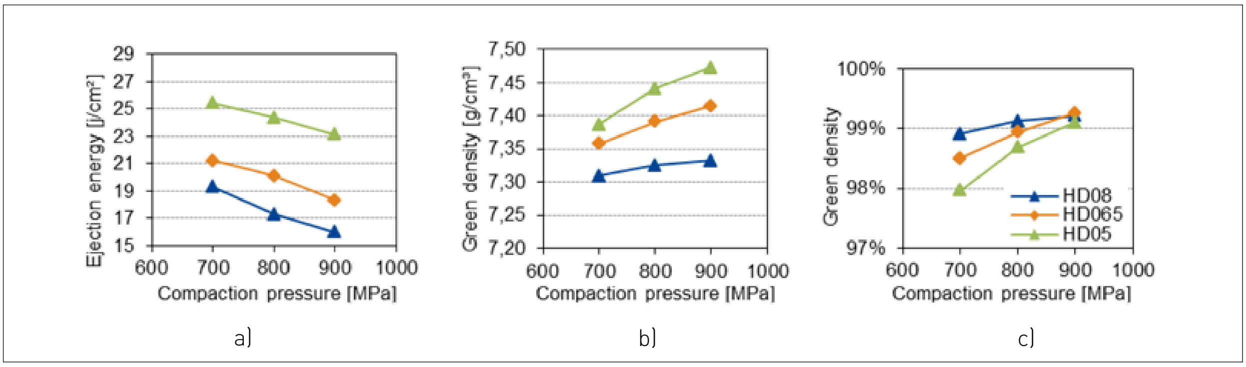


Fig. 10 a-c: Mix HD05, HD065 and HD08, ejection energy, green density and relative green density versus compacting pressure compacted at a tool die temperature of 90°C (Courtesy Höganäs AB, Sweden)

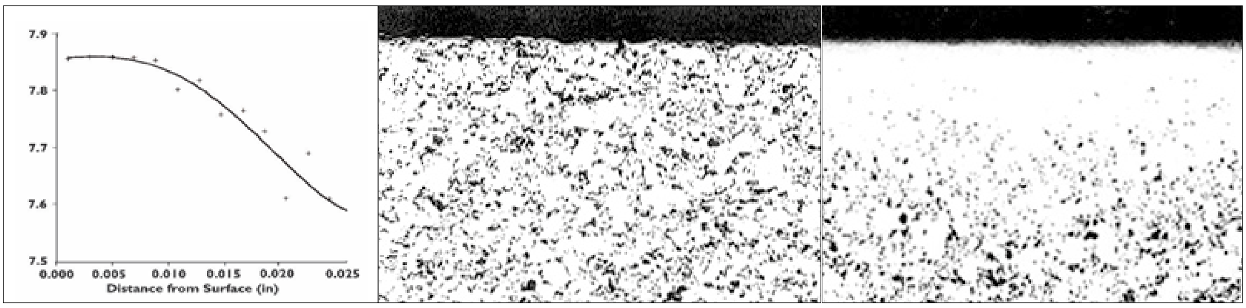


Fig. 11 (left) Density profile of selectively densified helical gear tooth flank; (middle) as-sintered density; (right) surface densified material (Courtesy Stackpole International, Canada).

Fig. 12 Surface densified engine balancer gear with 36° helix angle (Courtesy Stackpole International, Canada)

Fig. 13 A proprietary surface densification process forms the inner surface of this one-way clutch outer race to a minimum density of 7.7 g/cm³ (PMG Indiana Corporation, USA)

martensitic microstructure in sinter-hardening steels with close dimensional tolerances and very high levels of strength and hardness.

As discussed earlier, powder grades with compositions specifically tailored to respond to the cooling rates achievable in sinter-hardening, have been introduced to the market place in recent years. Case Study 4 presents a specific example of a sinter-hardened part.

Die wall lubrication

Whether compaction is cold or warm, a factor which is recognised as limiting maximum achievable green density is the volume fraction occupied by the relatively low density pressing lubricant and, for that matter, the graphite addition made to many ferrous mixes.

A number of developments have appeared, which have been aimed at reducing the required levels of ad-mixed lubricant. The Hoeganaes Corporation binder-lubricant, AncorMax 200, has already been mentioned in the context of Warm Die Compaction [51]. North American Höganäs has also reported on a lubricant, Intralube, that can be used at lower addition levels in combination with elevated die temperatures [62, 63, 64].

To go a stage further in reducing ad-mixed lubricant levels, the development of a reliable route for direct die wall lubrication has long been an objective of the PM structural parts industry. In recent years, a system has appeared which has been proved capable of doing this job reliably in a production compaction cycle [65]. This system involves the introduction of solid lubricant powder particles from a fluidised bed, via a charge gun and discharge block, mounted on the fill shoe. When the discharge block passes across the top of the die, the air/lubricant mixture is made to flow for a controlled time period and is attracted to the walls of the die cavity using electrostatic forces.

For relatively simple, single-level parts, this approach could eliminate ad-mixed lubricant entirely. For more complex multi-level parts, where many of the tooling element surfaces are hidden at the fill stage, some ad-mixed lubricant is likely to be required, one publication suggesting a level of 0.1-0.2 wt% depending on part geometry [66].

The potential for combining die wall lubrication and warm compac-

CASE STUDY 4

Sinter-hardened cam and bushing

Webster-Hoff Corporation and its customer ACCO Brand Inc. received a 2011 MPIF Award of Distinction in the hand tools/recreation category for this PM sinter-hardened cam and bushing used in a manual paper hole punching machine.

The cam transfers power to the cutters and the bushing supports the shaft. Both parts are formed to a density of 6.7 g/cm³ and have an ultimate tensile strength of 120,000 psi and an apparent hardness of 27 HRC.

Formed to net shape, the parts are sinter-hardened and tempered. The cam also receives a vibro-finishing operation and vacuum oil treatment.

The customer gained an annual cost saving of $410,000 by selecting PM rather than machining.

Fig. 14 Magnetic core of a reactor used in the boost converter of a hybrid vehicles, developed by Daido Steel Ltd and Toyota (Courtesy JPMA)

Fig. 15 The 32 part planetary assembly is used in a Ford HF35 hybrid transmission and was awarded an MPIF Grand Prize in 2014 (Courtesy MPIF)

tion has also been reported [67, 68]. At Toyota, researchers took the process one step further and by ramping up the pressure in warm compaction/die wall lubrication to almost 2000 MPa they achieved a green density of 7.85 g/cm^3 (or 99.9% of full density). They used the highly compressible ABC 100.30 iron powder with a warm compaction temperature of 150°C [69].

A subsequent collaboration between Toyota and Fine Sinter Company [70] has led to the introduction of a crankshaft timing chain sprocket and idle sprocket, processed by a variant on this warm compaction/die wall lubrication technology. Another Japanese producer, Hitachi Powdered Metals uses a combination of high pressure warm compaction (900 MPa) and die wall lubrication to produce a powdered stator core [71], which has subsequently been incorporated into a common rail diesel fuel injection system along with a PM magnetic armature assembled onto a steel shaft. A further example of a magnetic core made by warm compaction/die wall lubrication technology is shown in Fig. 14.

As a possible means of reducing the limiting effects of graphite additions on achievable green density, the approach has been investigated of reducing the graphite addition to the powder blend and instead introducing carbon from the atmosphere in sinter carburising.

Compaction press design

The die compaction of powders has now reached a very high level of sophistication, with geometrical complexity, height reproducibility and productivity as never before seen. Hydraulic and electric systems are increasingly gaining popularity over mechanical powder presses for many applications, with the exception of geometrically simple parts with large production volumes.

The high tonnage hydraulic presses used for complex components offer multilevel compaction with multiple lower and upper punches. More controlled punch movements are possible if the application justifies the extra expenses. Layered composites can by pressed from different powders, not just for hardmetal drill tips or valve seat inserts, but also for complex structural parts.

Electrical presses offer many environmental advantages and high productivity. These have been quite successful during recent years, especially in the hardmetal industry. The forming capabilities are, however, steadily extending into the domain of structural parts. With their many and rapid innovations, the cooperation between press and tool designers is opening the market for new PM applications .

Adding value through system assembly

The development of functional assemblies of PM parts has appeared in the market place in recent years, in that a number of parts makers have been seeking to create added value by moving downstream in the supply chain by delivering system or sub-system assemblies that incorporate a number of PM components.

A significant development, in this context, was that of the planetary carrier assembly of Keystone Powdered Metal Company, USA, for its customer, Ford Motor Company. This development was awarded an MPIF Grand Prize in the Automotive Transmission Category in 2014 (Fig. 15). The 32 part carrier assembly is used in the HF35 hybrid transmission that goes into Lincoln MKZ, Ford C-Max and Ford Fusion hybrid vehicles. The use of the powder forged helical gears, discussed earlier, has been central to this development, but Keystone's close relationship with the customer's designers has also allowed them to leverage opportunities for the incorporation of additional PM parts in the assembly. For instance, the spider and carrier plate are compacted and then sinter-brazed together before being joined to the shaft.

As originally designed, the assembly had only one Powder Metallurgy part. Keystone worked with Ford to optimise the design and drive cost out of the system. The planetary assembly now has seven PM components, which include a carrier spider, carrier plate, four Powder Forged helical pinions and a pump drive sprocket. It is estimated the customer has achieved cost savings of the order of 25% through adopting the Keystone assembly. In over two years of production of this carrier, with about a quarter of a million assemblies shipped, there have been no field returns.

A further leading example in this field is the PMG group's positioning of itself as a supplier of full synchroniser systems for manual and double clutch transmission applications. Rather than merely being a manufacturer of individual synchroniser components (hubs, rings, sliding sleeves, clutch cones, clutch dogs) by PM to customer designs, PMG is now recognised as a highly capable partner, when it comes to the design, testing and homologation of complete synchroniser systems with competitive advantages (Fig. 16)

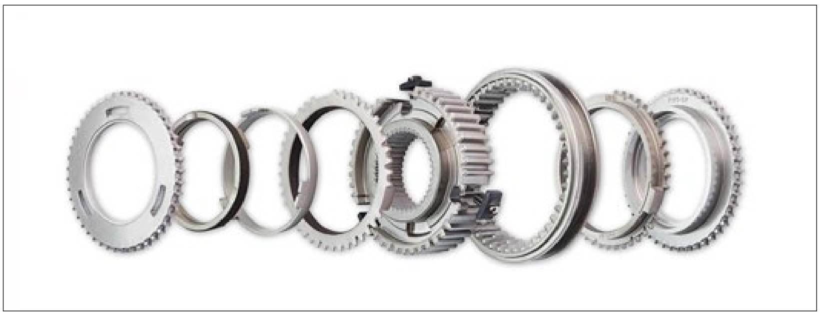


Fig. 16 Complete synchroniser systems for manual and double clutch systems are available from PMG (Courtesy PMG Group, Germany)

Fig. 17 The M32 six speed manual transmission, used in the SAAB 95 and other GM platforms has been modified by Höganäs to test a range of PM gears (Courtesy Höganäs AB, Sweden)

Fig. 18 SAAB 95 with a prototype PM 6 speed transmission (Courtesy Höganäs AB, Sweden)

PM gears for automotive manual transmissions

The manufacture of gears for automotive manual transmissions has long been viewed as a large potential market opportunity for PM. This market still remains to be penetrated but continues to excite significant development activity.

Höganäs AB has been particularly active in the incorporation of PM gears in demonstrator transmissions [72, 73, 74, 75]. After initial demonstrations in a SmartForTwo car and a World Rally Championship prepped Mitsubishi EVOX, Höganäs turned its attention, in May 2010, to the building of a demonstrator transmission for the high volume, passenger car market. The application chosen was a 6-speed manual transmission, the M32, used in the Saab 9-5 and Opel Insignia (Fig. 17).

All gears except the 1st, 2nd and reverse drive gears (machined directly into the gearbox shaft) were evaluated for replacement by PM [73, 74]. Analyses indicated that the reverse idler and 3rd and 4th speed gear pairs could be viable as PM parts in a case hardened 0.85% Mo

Fig. 19 4th speed rolled manual transmission gear (Courtesy GFT/GKN)

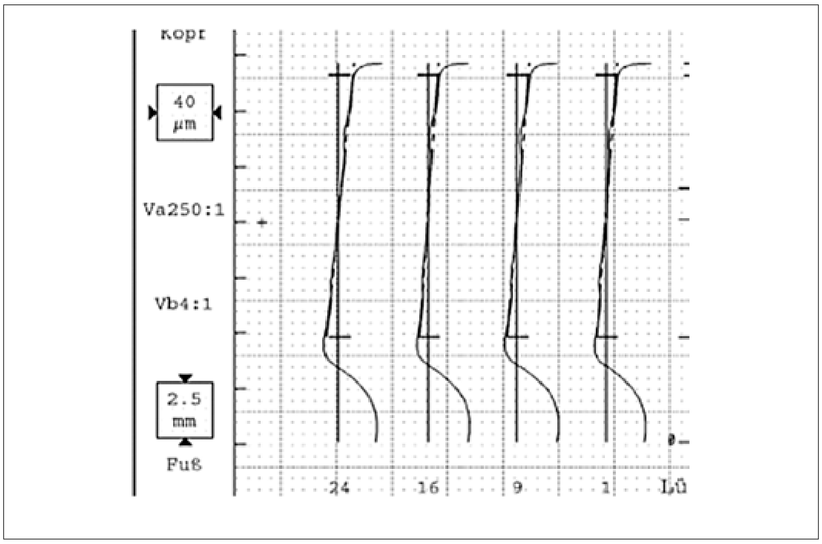


Fig. 20 Tooth profile after rolling (DIN Q5) including protuberance for subsequent hardfinishing operation (Courtesy GKN)

pre-alloyed steel (Astaloy 85Mo) at a density of 7.25 g/cm^3. The 5th and 6th speed gear pairs would need higher performance, either through increasing the density of the Astaloy 85Mo material to 7.4 g/cm^3 (for example, by using double press-double sinter processing) or the application of a post-sintering process such as super-finishing or shot-peening. The 1st and 2nd speed driven gears would need the application of surface densification or the incorporation of more radical gear design modifications (the redesign of the tooth root geometry to reduce bending stresses for example, by the use of an asymmetric tooth profile). PM has a competitive advantage here as it has the capacity to form tooth profile designs that are not feasible by gear hobbing.

Höganäs was proceeding, during 2014, to verify these conclusions by building and testing a prototype transmission with the relevant PM gears in a Saab 95 vehicle (Fig. 18).

Getrag Ford Transmissions and GKN Sinter Metals have also been involved in assessing the viability of PM gears in a high volume manual transmission. Due to the high performance requirements of these gears, the compaction and sintering of a specifically designed gear preform is followed by a transverse rolling operation, delivering a tailored density distribution in the teeth with full density at the surface layer. Helical compaction of a gear with a helix angle of ß = 34° (Fig. 19), generating the protuberance within the rolling process (Fig. 20) as well as case hardening and hard finishing have been executed under serial production conditions within a collaborative development program.

The results of these assessments were presented by Dr Thomas Rochlitz of Getrag in a contribution to a special interest seminar at Euro PM2014, Salzburg, September 2014. Dr Rochlitz reported that the test work had already verified the technical viability of the 4th speed manual transmission PM gears and that testing was underway, which was expected to verify the viability of the transmission gears.

However, the point was emphasised that technical viability is not sufficient to ensure market penetration; the economics must also be favourable. PM solutions would only penetrate the market if they could influence a gearbox manufacturer's investment decision at the time that new machining capacity was needed. Therefore, PM could not hope to be competitive on a "marginal cost basis" if the necessary machining capacity for the steel gears route was already available, specifically in the case where the gear bodies are of a simple shape.

This is not an uncommon situation in the supply of high-volume automotive parts and one that would undoubtedly have been an issue faced in the early days of PF connecting rod development, for instance. However, the proving of technical viability of PM solutions in these programs has positioned PM to be "in the right place at the right time" when future investment decisions are made on machining capacity. The prospects for eventual penetration of this market are therefore being enhanced.

Concluding remarks

Trends in the content of programmes of PM international conferences may provoke the conclusion that most of the innovation potential now rests with emerging processes, such as additive manufacturing for example.

However, ferrous structural part manufacture still remains the bedrock of the PM industry and it is hoped that this article has provided ample evidence that the sector's capacity for innovation and entrepreneurial spirit are still alive and kicking.

Author

David Whittaker
DW Associates
231 Coalway Road, Wolverhampton
WV3 7NG, United Kingdom
Tel: +44 (0)1902 338498
Email: david-dwa@blueyonder.co.uk

References

[1] P Lindskog, Sintered ferrous structural components in the 21st century, Proceedings of PM Automotive Applications Conference, India, 1997, pp. 25-34
[2] Hoganas AB, *International Journal of Powder Metallurgy*, Vol. 36, No. 1, Jan/Feb 2000, pp. 11-12
[3] Hoeganaes Corporation, Leading the Bonding Revolution, *Metal Powder Report*, Vol. 58, No.10, October 2003
[4] H Suzuki and S Nishida, Properties of new segregation-free powder for high density applications, Advances in Powder Metallurgy and Particulate Materials – 2007 Proceedings, Denver, 2007, Part 3, pp. 11-18, MPIF
[5] P King, S Patel, S Shah, J Falleur and B Wewers, Lower molybdenum steels for high performance Powder Metallurgy applications, Advances in Powder Metallurgy and Particulate Materials – 2006, San Diego, 2006, Part 7, pp. 81-94, MPIF
[6] M Johansson, Expanding opportunities with chromium, *Metal Powder Report*, Vol. 54, No. 3, March 1999, pp. 22-24
[7] U Engstrom, D Milligan and A Klekovkin, Mechanical Properties of High Performance Chromium Materials, Advances in Powder Metallurgy and Particulate Materials – 2006, Proceedings, San Diego, 2006, Part 7, pp. 21-32, MPIF
[8] M Dahlstrom, M Larsson and Y Giraud, High Performance PM Components Heat Treated by Low Pressure Carburising and Gas Quenching, Euro PM2013 Conference, Gothenburg, 2013, EPMA
[9] A Klekovkin, N Nandivada and I Howe, Fatigue Performance of cost-effective Cr-Ni pre-alloyed PM steel, designed to replace Fe-Ni steels and match wrought steels, Advances in Powder Metallurgy and Particulate Materials – 2009, Proceedings, Las Vegas, 2009, Part 7, pp. 73-84, MPIF
[10] P King, Chromium Containing Materials for High Strength-High Fatigue Applications, World PM Congress, Vienna, 2004, EPMA
[11] P King and B Lindsley, Performance Capabilities of High Strength Powder Metallurgy Chromium Steels with two different Molybdenum Contents, Advances in Powder Metallurgy and Particulate Materials – 2006, Proceedings, San Diego, 2006, Part 7, pp, 1-11, MPIF
[12] P King and B Lindsley, Chromium Steels for High Performance PM Applications, Advances in Powder Metallurgy and Particulate Materials – 2007, Proceedings, Denver, 2007, pp. 1-11, MPIF
[13] B Lindsley, Development of a High Performance Nickel-free Steel Proceedings of World PM Congress, Vienna, 2004, EPMA
[14] W B James, B Lindsley and K S Narasimhan, Paper at PM 2012 Powder Metallurgy World Congress, Yokohama, Japan, 2012, JPMA
[15] B Lindsley, C Schade and H Rutz, High performance Manganese-containing PM steels, Advances in Powder Metallurgy and Particulate Materials – 2008, World PM Congress, Washington D C, 2008, Part 7, pp. 17-25, MPIF
[16] M J Dougan and J Morato, New robust Mn-based PM steels, Advances in Powder Metallurgy and Particulate Materials – 2008, World PM Congress, Washington D C, 2008, Part 7, pp. 35-42, MPIF
[17] U Engstrom, C Larsson, S Berg and C Szabo, Technologies for PM growth Special Interest Program, PowderMet 2013, Chicago, 2013, MPIF
[18] S St-Laurent and J Campbell-Tremblay, PM 2014 World Congress on Powder Metallurgy and Particulate Materials, Orlando, 2014, MPIF (and summarised in *Powder Metallurgy Review*, Winter 2014)
[19] F Chagnon and C Cosana, 2012 Powder Metallurgy World Congress, Yokohama, Japan, 2012, JPMA
[20] F Chagnon, M Moravej and J Campbell-Tremblay, 2012 Powder Metallurgy World Congress, Yokohama, Japan, 2012, JPMA
[21] T Muetani, S Unami, Y Ozaki and Y Yaranishi, Special Interest Seminar on Lean Steels, Euro PM 2013, Gothenburg, 2013, EPMA
[22] P K Jones, K Buckley-Golder, R L Lawcock and R Shivanath, Densification Strategies for High Endurance PM Components, *International Journal of Powder Metallurgy*, Vol. 33, No. 3, April/May 1997, pp. 37-44
[23] R Shivanath and P K Jones, US Patent 5,516,483, 1996
[24] M J Dougan, K Lipp and A Glaser, Highly dense PM components for high performance applications, Proceedings of Euro PM2008 Conference, Vol. 1, pp. 169-174, EPMA
[25] M Sarasota, S Sainz and F Castro, Liquid Phase Sintering of PM Steels through Boron-containing Master-alloy Additions, Proceedings of Euro PM2006 Conference, Prague, 2006, Vol. 1, pp. 349-356, EPMA
[26] F Castro, S Sainz, V Martinez and M Dougan, Sinterability, Hardenability and Mechanical Properties of Mn-containing PM steels through the use of a Specially Developed Fe-Mn-C Masteralloy, Advances in Powder Metallurgy and Particulate Materials – 2006, Proceedings, San Diego, 2006,

Part 7, pp. 95-108, MPIF
[27] F Castro and W Garcia, Lean and high-strength PM steels for sinter-hardening , Advances in Powder Metallurgy and Particulate Materials – 2009, Proceedings, San Diego, 2009, Part 5, pp, 65-78, MPIF
[28] J Capus, Sinter hardening looks ahead, *Metal Powder Report*, Vol. 55. No. 11, November 2000, pp. 19-21
[29] P Sokolowski, B Lindsley and F Hanejko, Introduction of new sinter-hardening PM steel, Advances in Powder Metallurgy and Particulate 2008, Part 7, pp. 43-51, MPIF
[30] W B James, Cost-effective sinter-hardenable ferrous PM materials, PM Asia 2009 Conference, Shanghai, 2009, Elsevier
[31] W B James, B Lindsley, H Rutz and K Narasimhan, Lean hybrid low-alloy molybdenum steels, Euro PM2009, Copenhagen, 2009, EPMA
[32] B Lindsley, Sinter-hardening response of leaner alloy systems, Advances in Powder Metallurgy and Particulate Materials – 2009, Proceedings, Las Vegas, 2009, Part 7, pp. 85-96, MPIF
[33] I Howe, R Warzell, D Milligan, A Klekovkin and Y Yu, Performance characteristics of newly developed sinter-hardened PM steel, Advances in Powder Metallurgy and Particulate Materials – 2008, World PM Congress, Washington D C,2008, Part 7, pp. 250-263, MPIF
[34] M Gauthier, S Pelletier, M Korotkin, S Metcalfe and T Stephenson, Improved sinter-hardenability by extra-fine nickel additions, Euro PM2009 Conference, Copenhagen, October, 2009, EPMA
[35] F Castro, A Karuppanagounder and S Sainz, Hardenability and mechanical properties of novel sinter-hardening PM steels, Advances in Powder Metallurgy and Particulate Materials – 2009, Proceedings, Las Vegas, 2009, Part 10, pp. 52-61, MPIF
[36] S Saccarola, G Bellin, S Bueno, F Castro and S Sainz, Novel high performance and dimensionally stable PM steels for sinter-hardening, Euro PM 2009, Copenhagen, 2009, EPMA
[37] F Castro, A Karuppanagounder, S Sainz, S Saccarola, G Bellin and S Bueno, Influence of selected alloying elements on the hardenability and mechanical properties of recently developed sinter-hardening PM steels, Euro PM2009, Copenhagen, 2009, EPMA
[38] F Castro, S Sainz and S Saccarola, Comparative study of hardenability and mechanical properties of sinter-hardening PM low alloy steels, Euro PM2009, Copenhagen, 2009, EPMA
[39] G Rau ad P Delarbe, PowderMet 2011, San Francisco, 2011, MPIF
[40] M Weber, Comparison of Advanced Procedures and Economics for production of Connecting Rods, *Powder Metallurgy International*, Vol. 26, No. 3, pp. 125-128
[41] M Weber, Powder Forging of Automotive Connecting Rods, Paper C427/31/227, Autotech 1991, I Mech E
[42] E Ilia, K Tutton and G Lanni, Paper in Technologies for PM growth Special Interest Program at PowderMet 2013, Chicago, 2013, MPIF (and summarised in *Powder Metallurgy Review*, Autumn/Fall 2013)
[43] I Donaldson, T German and R Williams, PowderMet 2011, San Francisco, 2011, MPIF
[44] E Ilia, 2014 World Congress on Powder Metallurgy and Particulate Materials, Orlando, 2014, MPIF (and summarised in *Powder Metallurgy Review*, Winter 2014)
[45] P Whittaker, Keystone Powdered Metal Company: Pioneering the Powder Forging of automotive helical pinion gears, *Powder Metallurgy Review*, Autumn/Fall 2014, pp. 44-52
[46] P Blanchard, High Density under Cold Single Pressing Operation; New Applications, Euro PM97 Conference, Munich, 1997, pp. 44-50, EPMA
[47] P Blanchard, High Density on PM Parts for Automotive Starter, SAE Technical Paper No. 980332, 1998
[48] Press makers signal faith in warm compaction, *Metal Powder Report*, Vol. 49, No. 7/8, p.24, 1994
[49] Hoeganaes offers higher density at lower cost, *Metal Powder Report*, Vol. 49, No. 7/8, pp. 22-24, 1994
[50] The cutting edge in PM automotive parts article in PM's driving force in North America, *Metal Powder Report*, Vol. 56, No. 10, 2001, pp. 8-9
[51] F Hanejko, High Density via Single Pressing/Single Sintering, Euro PM2007, Toulouse, 2007, Vol. 3, pp. 15-20, EPMA
[52] F Hanejko and H Rutz, Single Press/Single Sinter solutions to high density, Euro PM2009, Copenhagen, 2009, EPMA
[53] F Hanejko and S Clisby, Technologies for PM growth Special Interest Program, PowderMet 2013, Chicago, 2013, MPIF
[54] G Falleur, S Shah, F Hanejko and S Patel, PM2014 World Congress on Powder Metallurgy and Particulate Materials, Orlando, May 2014
[55] P Knutsson and M Larsson, Euro PM2014, Salzburg, September 2014, EPMA
[56] Y Takeya, T Hayasaka, M Suzuki and A Kamada, Surface rolling of sintered gears, SAE Paper 820234, 1982
[57] D Sarafinchan, P K Jones, K Buckley-Golder and H David, Powder Metal Bearings and Gears with Steel-like Performance, SAE Technical Paper 2001-01-0401, 2001
[58] R L Lawcock, K Buckley-Golder and D Sarafinchan, Testing of High Endurance PM Steels for Automotive Gearing Components, SAE Technical Paper 1999-01-0293, 1999
[59] R L Lawcock, H David and M Renahan, Design and Development of Automotive Transmission Pinions, Advances in Powder Metallurgy and Particulate Materials – 2007, Proceedings, Denver, 2007, Part 12, pp. 1-12, MPIF
[60] S Nigarura, R Parameswaran and J Trasorras, Bending Fatigue of Surface Densified Gears; Effect of Root Densification Depth and Tooth Loading Mode on Fatigue Life, Advances in Powder Metallurgy and Particulate Materials – 2006, Proceedings, San Diego, 2006, Part 12, pp. 22-35, MPIF
[61] S Dizdar, PM Materials for Gear Applications, Euro PM2007, Toulouse, 2007, Vol. 1, pp. 129-134, EPMA
[62] D Milligan, P Hofecker, I Howe, S Miller and O Litstrom, Performance characteristics of a newly developed PM lubricant used in combination with elevated die temperatures,

Advances in Powder Metallurgy and Particulate Materials – 2008, World PM Congress, Washington D C, 2008, Part 3, pp. 1-10, MPIF
[63] M Larsson, A Ahlin and S Miller, Performances of mixes with new lubricant system based on chromium-alloyed powders, Advances in Powder Metallurgy and Particulate Materials – 2009, Proceedings, Las Vegas, 2009, Part 3, pp. 1-13, MPIF
[64] M Larsson, A Ahlin and K Olsson, High performance mixes with new lubricant system, Euro PM2009, Copenhagen, 2009, EPMA
[65] W G Ball, P F Hibner, F W Hinger, J E Peterson and R R Phillips, New Die Wall Lubrication System, *International Journal of Powder Metallurgy*, Vol. 33, No. 1, 1997, pp, 23-30
[66] P Lemieux, Y Thomas, P-E Mongeon, S Pelletier and S St-Laurent, Benefits of Die Wall Lubrication for Powder Compaction, Advances in Powder Metallurgy and Particulate Materials – 2003, Part 3, pp.16-25, MPIF
[67] P Lemieux, Y Thomas, P-E Mongeon, S Pelletier and S St-Laurent, Combining Electrostatic Die Wall Lubrication and Warm Compaction to Enhance Green Properties of PM Components, Advances in Powder Metallurgy and Particulate Materials – 2002, Part 3, pp.34-46, MPIF
[68] T Kohida and Y Yamanishi, Development of die wall lubrication technique for multi-stepped mould, Advances in Powder Metallurgy and Particulate Materials – 2008, World PM Congress, Washington, 2008, Part 3, pp. 126-138, MPIF
[69] M Kondo et al, High Density Powder Compaction Using Die Wall Lubrication, Advances in Powder Metallurgy and Particulate Materials – 2002
[70] T Monya et al, Development of Die Wall Lubricated Automotive Engine sprockets, Proceedings of World PM Congress, 2004, EPMA
[71] S Saitoh, M Iwakari and T Kagaya, Properties of Sintered Materials produced by Densification Process combining Warm Compaction and Die Wall Lubrication, *Hitachi Powdered Metals Technical Report*, No. 2, 2003, pp. 36-43
[72] A Flodin, Euro PM2014, Salzburg, 2014, EPMA
[73] A Flodin and P Karlsson, PM2012 Powder Metallurgy World Congress, Yokohama, Japan, 2012, JPMA
[74] A Flodin and M Andersson, PM2012 Powder Metallurgy World Congress, Yokohama, Japan, 2012, JPMA
[75] A Flodin, *Powder Metallurgy Review*, Spring 2014, pp. 45-53

Increasing quality and productivity in PM through automated handling systems

There can be a high risk of damage to green parts though poor handling procedures during the production process. The increased complexity of PM parts makes them ever more susceptible to cracks when in the green state. Automation of the handling of parts through all stages of production, from powder press to sizing press, can prevent costly failures, leading to improved quality and increased productivity. Lutz Lackner of Dorst Technologies GmbH describes a number of options available when considering the automation of handling systems.

The production of compacts made from metal powder has reached a high level of quality and offers a geometrical range that extends from relatively simple to complex multi-level parts with high tolerances. In the green state these parts are often highly sensitive and susceptible to rough handling. If not treated carefully they are at risk of damage, which can often only be identified by extensive inspection methods at high cost. Such components, therefore, demand automatic handling systems to transfer them from the press to the furnace, eliminating manual interference and minimising the risk of damage.

Also, during the sizing process there is a need for automatic part recognition and handling to ensure a safe, reproducible and fast process. With respect to this production step the necessity is for perfect recognition of part geometry, alignment with the tool and safe transfer across the machine to the tool cavity.

The options for automation of such tasks are based on the individual parts to be produced and the various requirements at each production site, driven by production philosophy and the different local infrastructure. Therefore the task has to be taken care of very thoroughly, to fulfil the requirements in accordance with the part geometry and its specific handling challenges. This often results in a custom made handling

Fig. 1 A robot removes the green compact from the press

Fig. 2 Powder press TPA1200/3HP equipped with a robot for part removal


Fig. 3 A six-axis jointed-arm robot can be used to remove green parts from the powder press

system, specifically developed for each application. There is of course a pool of established and proven handling technologies available to do this job. These include linear handling systems, SCARA robot systems and six axes robots. They can be combined with different types of compacting and sizing presses including mechanical, hydraulic and electric presses.

Automation of powder presses

As previously stated, following the pressing process green parts are very sensitive. Their thin chamfers are likely to break following even the slightest impact, making the entire compact useless. Manual handling of green parts bears the risk of damage due to the variation in handling techniques between different employees and the variation in handling required by the different parts.

To avoid damage it is essential to provide an even and constant force applied to the same area of every green compact, representing a reliable and repeatable process. The optimum method to handle the sensitive green part is therefore a fully automated system. The basic necessary functions required to achieve this goal are:

- To remove the compact from the press
- To place the compact onto a conveyor or sinter carrier

These can, however, be upgraded by complementary operations that include:

- Checking part weight
- Dimensional checks
- Deburring of parts
- Change of sinter carrier
- etc

Systems for removal of compacts from the press

The simplest way to remove a pressed part is to push it off the press using the filling shoe. This is only possible with comparatively robust compacts, which are mainly produced on mechanical powder presses. In this case the parts leave the press via a chute and/or a conveyor belt. The parts will be not aligned in any way.

When it is necessary to maintain the orientation of the compact for a secondary process step a gripper is mandatory. The gripper may be attached to the filling shoe, which is the most appropriate solution for mechanical presses as it ensures a synchronous movement without

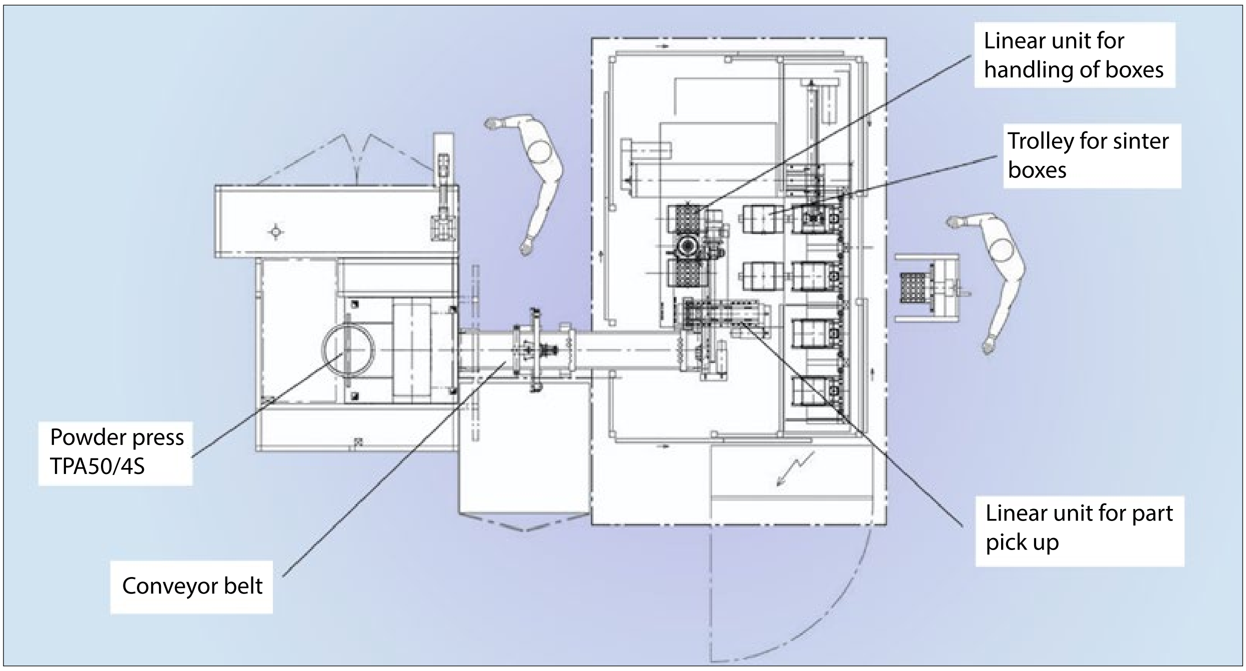


Fig. 4 High speed powder press TPA50/4S with linear handling system

the need for an additional drive or control. Alternatively, the gripper can be installed with its own independent drive unit and electronic controller. This represents a much more sophisticated system allowing more options for individual movements.

Finally, there are robot systems, either a SCARA robot or a six-axis jointed-arm robot (Figs. 2 and 3). Such systems offer the highest flexibility in handling different parts and perform complementary tasks, however they require the highest level of operation and control systems.

Placing compacts onto sinter devices

Linear system combined with a mechanical press

An example of this method can be seen in Fig. 4 where a mechanical high speed press type TPA50/4S is combined with a linear handling system. The green parts are pushed off by the filling shoe and slide over a chute to a conveyor belt running at a constant speed. The system operates at a production rate of 50 spm.

On the conveyor belt an additional device is required to position the compacts in fixed place, from where they can be picked up. In this case a mechanical device gathers the parts and keeps them in a defined position as programmed into the gripper system. After collecting five compacts a signal is generated and sent to the controller of a linear unit, which picks up the pressed parts from the conveyor and carries them to a sinter box located on a rotating table. As soon as the box is filled with compacts an empty box is provided by a table rotation of 180°. The loaded box is then picked up by a second linear unit and placed onto furnace trolleys which accept up to 20 loaded sinter boxes. When a trolley is fully loaded it will be manually moved to the sinter furnace.

This system represents a simple and economical solution and at the same time offers the option for maximum production output. Therefore such systems can often be found in combination with mechanical high speed presses, where they operate at production rates up to 70 spm.

"This system represents a simple and economical solution and at the same time offers the option for maximum production output"

Robot system combined with a mechanical press

Another solution is the combination with a six-axis jointed-arm robot as shown in Fig. 5. Again a mechanical speed press type TPA50/4S delivers the green parts, in this case from a double cavity tool. A gripper system attached to the front side of the filling shoe picks the parts and places them onto a two-track conveyor. The conveyor forwards the compacts to a robot which picks them up and places them directly onto the furnace belt in a programmed configuration.

This layout represents a fully automated solution, transferring the pressed parts from the powder press onto the furnace belt, without any manual interference. Since a double cavity tool is applied, 100 parts per minute are handled at a stroke rate of 50 spm.

Both the described linear and robot automation systems are examples of how to handle a large volume

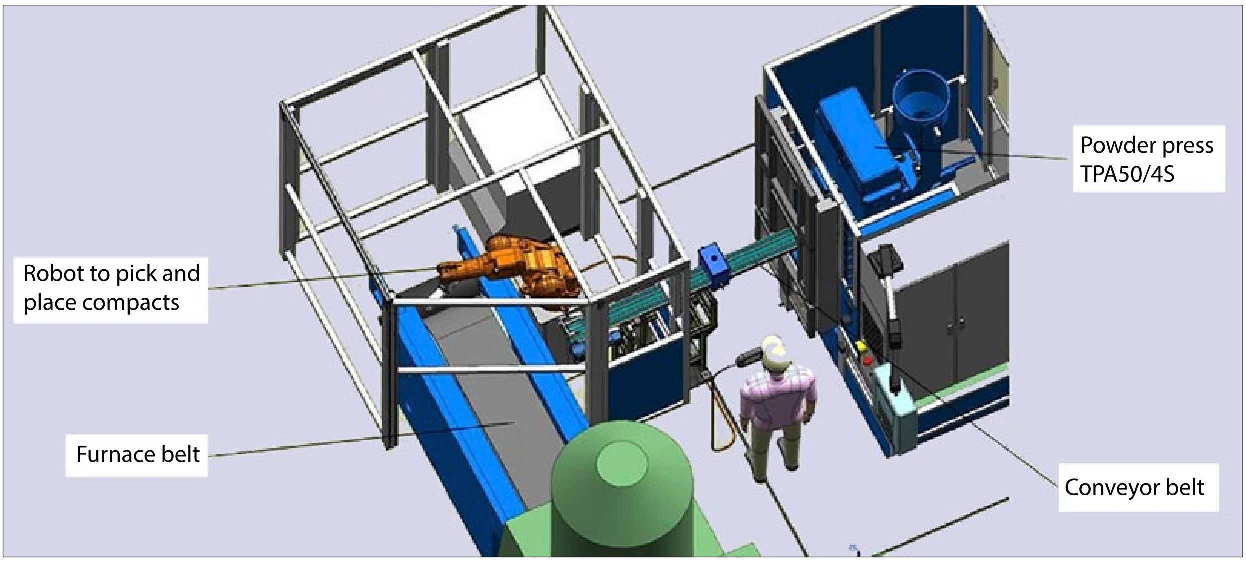


Fig. 5 High speed powder press TPA50/4S with robot automation system

production of compacts safely in an economical way. Of course, they are designed for a defined family of parts with similar shape and thus are somewhat limited in flexibility to match other compact geometries.

Robot system combined with CNC - presses

When the range of products comprises various geometrically different parts, which ask for highly sensitive pick up, the most appropriate solution is a freely programmable robot system. Only a robot offers the option to be adjusted to a large array of various geometries and there are many gripper systems to adapt it to various tasks. In general, robots have got their own electronic control system and can be synchronised with all relevant movements of the powder press. This makes this kind of automation the preferred solution in combination with closed loop controlled powder presses. The combination of a six-axis jointed-arm robot with a hydraulic closed loop controlled powder press TPA250/3HP is shown in Fig. 6.

In order to save valuable floor space the robot is assembled overhead onto a portal frame, fixed at the part exit side of the press. Its task is to pick up the part directly from the die in the centre of the press and to place it outside the press structure. In most cases this is a scale to ensure accurate green part weight.

To adapt to different part geometries the robot can use various grippers. These include individually formed gripper fingers, vacuum elements and inner diameter grippers. The choice depends on the geometry of the component to be handled. The gripper is then individually adapted to suit, thus presenting the optimum solution.

When it comes to the change for production of another component, the gripper is replaced along with

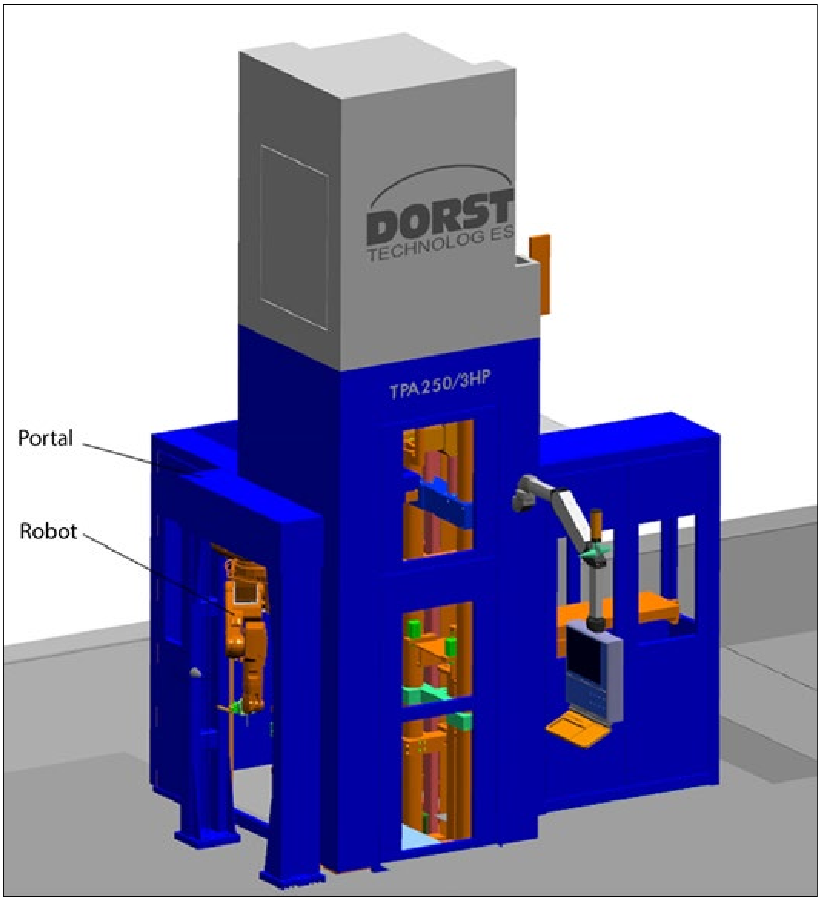


Fig. 6 Hydraulic CNC Powder press TPA250/3HP with 6-axis overhead robot

the tool elements on the press. This procedure grants the optimum pick up device for each individual part with a minimum risk of causing damage by the handling system.

Today's gripper systems offer the option for quick action clamping, making the task of changing them easy and eliminating any adjustment. After assembly the position of the gripper is already in perfect alignment with the tool and the handling system, thus resulting in accurate positioning without wasting time.

Further handling may involve a conveyor belt assembled to the scale, which then forwards the compact to the next conveyor en route to the sintering furnace. In certain situations a second robot can be installed to pick up the compact from the first position and forward it to the next. This robot may also identify parts that are not within weight tolerances and can be engaged for additional tasks such as deburring or dimensional checks. In this combination the double robot automation will outperform every other possibility with regard to flexibility and versatility.

In order to simplify the process for the operator, the control system DVS/DCS® of the Dorst powder presses integrates the programming of the robot into the press controller. The operator only has to program a number of key individual part related parameters and need not worry about the general positions and movements. These are calculated by the DVS/DCS® system and then transferred from the press controller to the robot control system. This is a dynamic action that also considers the actual die position during continuous operation, which may be necessary due to the action of the automatic filling height adjustment actuated by the press.

The achievable stroke rate depends on the following scenarios:

- If one robot picks up and places the compact to a fixed location, the maximum output is achieved
- If the same robot has to pick up the part again after weighing and only then place to its final position, the output is reduced remarkably
- The combination of two robots is capable of performing additional tasks, such as deburring, and still reaches the maximum stroke rates.

Automation of sizing presses

Generally, during powder pressing, the orientation of the compact is not important for the handling system. On a sizing press, however, the correct positioning of the compact is essential. The most important task for this process is to recognise the part's geometry and ensure that accurate orientation is maintained until it enters the tool.

The compacts fed to the sizing press have to be automatically identified and then forwarded. At first the orientation (upside/downside) of the compact has to be checked carefully. Any parts not meeting the criteria need to be removed at this stage and not be forwarded to the press feeder. A visual identification of the part geometry and its position are accomplished by camera systems with corresponding software, which are the most appropriate solution for this task. The information about the orientation is evaluated by a SCARA robot, which aligns the compact correctly to the geometry of the die by rotation. Only parts accurately oriented and rotationally aligned will

Fig. 7 Hydraulic CNC sizing press TPA250K with robot part loading system

be sent into the feeder system by the SCARA robot.

The on time transfer of the compacts to the individual stations has to be synchronised with the vertical movement of the press for the sizing and/or coining/chamfering movement. The first choice to comply with this task is a walking beam system, comprising linear bars carrying one gripper pair per every station. The distance between the gripper pairs matches the distance between the individual positions, in which the compact has to be placed during its transfer through the press.

The gripper movement of the walking beam is closed loop controlled. In every position there are specifically configured gripper claws to properly keep the part. During the reversal movement of the walking beam, when the grippers have to be open, the parts are fixed on the feeder plate by pneumatically actuated hold down devices. When the grippers are closed for the next forward move they double check that the compacts still fit to the claws. Each deviation will be recognised and signalled to the press controller DVS/DCS®, which will immediately stop the movement of the transfer function.

Additionally, during the pressing/sizing cycle every part is monitored to ensure the programmed pressing force limits are met. If the minimum force is not reached, the compact will be separated, or, in the case of exceeding the maximum force, the press will stop immediately.

As well as the monitoring tasks and the required accuracy in positioning in the application of sizing, speed is also of high importance. The automation system has therefore to be capable of running at stroke rates up to 25 min^{-1}, which are achieved, for example, by the sizing press type TPA250K, shown in Fig. 7.

Conclusion

The task of handling green components needs careful consideration since every part geometry has its own individual handling challenges. Additionally, there are specific requirements at each production site due to the existing local infrastructure and space availability. These considerations lead to custom made solutions, developed for each individual application.

The prevention of manual handling of green compacts offers several benefits. Automation solves the technical issues that require an even and constant force when handling the compacts. It allows for the same area of contact on each part, with individually adapted grippers for each geometry. There are also additional economic aspects to automation such as the ability to operate 24/7.

Within the production process of powder pressing and sizing of compacts there are many opportunities to damage parts. In order to avoid this risk manual interference should be limited to an absolute minimum in production. Automated systems are the only way to ensure faultless delivery of green components from the powder press to the sintering furnace.

Automatic part handling systems are a well proven and an economical alternative to manual handling and are established at many production sites already.

Author

Lutz Lackner
Dorst Technologies GmbH & Co. KG
Mittenwalder Str. 61
82431 Kochel am See
Germany
Email: Lutz.Lackner@dorst.de


Connecting Global Competence
Messe München International
Hot spot for the ceramics industry
The perfect recipe for success.
ceramitec 2015 is the surefire way to give your business the competitive edge. Exhibit at this leading international exhibition and enjoy the benefits of a truly professional forum:
· Full coverage of the ceramics sector.
· High-caliber trade audience from around the world.
· Professional services for exhibitors.
Don't delay. Sign up today!
To register:
www.ceramitec.de/application
ceramitec 2015
Technologies · Innovations · Materials
October 20 – 23 · Messe München
ceramitec.de

3rd International

Conference in Kyoto, Japan

APMA 2015

Date

November 8 (Sun)—10(Tue), 2015

Venue:

Kyoto University Clock Tower Centennial Hall

on Powder Metallurgy in Asia

Organized by

Japan Society of Powder and Powder Metallurgy (JSPM)

Japan Powder Metallurgy Association (JPMA)

Powder Metallurgy in India: A dynamic industry on show at PM-15

The PM-15 International Conference & Exhibition on Powder Metallurgy and Particulate Materials and the 41st Annual Technical Meeting of PMAI, organised by the Powder Metallurgy Association of India (PMAI), took place at the Victor Menezes Convention Centre, located in the picturesque surroundings of Indian Institute of Technology, Bombay, from January 19 - 21, 2015. In this exclusive report for *Powder Metallurgy Review*, Professor Ramamohan Tallapragada, PM Consultant, Mumbai, India, provides an overview of the conference.

This year's PM-15 conference and exhibition was held in Mumbai, India's largest city and recognised as the country's business capital. The popular event, organised by the Powder Metallurgy Association of India (PMAI), was co-hosted by the Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology, Bombay (IITB). The conference included some 98 presentations made in six plenary sessions and three parallel sessions. There was a special interest session on Developments in Engineering Ceramics and an exhibition that showcased the latest in PM technology, equipment and services (Fig. 1).

PM-15 began with an Inaugural Ceremony in which the Conference Chairman, Professor P Ramakrishnan, introduced the event and welcomed delegates. During his opening speech he discussed the growing importance of Powder Metallurgy as an alternate technology in automotive and engineering industries. Prof Ramakrishnan illustrated the uniqueness of PM in developing tungsten based components and nickel based super alloy components in defence applications. The President of the PMAI, N Gopinath,

Fig. 1 Manohar Parrikar, India's Defence Minister (left), opened the PM-15 exhibition and was shown around by the PMAI President N Gopinath. Here he meets Greg Lavallee and Vania Grandi of Rio Tinto (QMP)

Fig. 2 The opening address (From left to right: Convener Prof P Ramakrishnan, Prof T R Rama Mohan Co. Convener, Hon. Manohar Parrikar Defence Minister of India, N Gopinath President PMAI, Dr Subhasish Chaudhury, Deputy Director IIT Bombay and Dr K Murli Gopal Treasurer PMAI)

Fig. 3 India's Defence Minister, Hon. Manohar Parrikar delivering his inaugural address

followed and spoke about the role played by the association in developing the PM Industry in India. Gopinath also listed the capabilities of the Indian PM industry and highlighted its readiness to manufacture components to defence requirements.

Prof T R Rama Mohan introduced the Chief Guest at PM-15, India's Defence Minister, Hon. Manohar Parrikar. Prof Rama Mohan stated that after graduation from IITB in metallurgical engineering Parrikar worked at RK Hydraulics as an engineer. Following this he started his own hydraulic company, Goa Hydraulics. Parrikar designed and built a number of systems and also developed machined biomedical implants. Prof Rama Mohan concluded that as India's first Defence Minister with a qualification in metallurgical engineering, and a knowledge of engineering from the shop floor up, coupled with his innovative spirit, Parrikar is uniquely suited to the position.

"Parrikar stressed the importance of Powder Metallurgy components in defence applications"

In his inaugural address Parrikar stressed the importance of Powder Metallurgy components in defence applications, such as in armour, penetrators, gun components etc (Fig. 3). He urged PM corporate, academic and research establishments to come forward and work in areas related to defence applications. Parrikar assured full cooperation and promised to simplify procedural obstacles that hinder vendors intending to supply the defence sector. He had requested research students and scientists to focus their research on innovative components and processes that can help in the defence of the country.

The PMAI's international conferences have been opened by Parrikar twice before in Goa, once as leader of the opposition and once as Chief Minister of Goa. In recognition of his support and encouragement, the PMAI bestowed its fellowship award (Fellow of PMAI) on Parrikar (Fig. 4).

Fig. 4 N Gopinath presented India's Defence Minister, Hon. Manohar Parrikar, with Fellow of PMAI Award (FPMAI)

Exhibition emphasises applications of PM in automotive, engineering and defence industries

The PM-15 exhibition included representatives from some 27 national and international companies. Parrikar opened the exhibition and was given a guided tour. He met with numerous exhibitors and discussed their products and the advantages of using PM technology. The minister stated the emphasis of India's Government is on making products in India and seeing that necessary skills are developed.

While the majority of the PM industry in India is well established and caters for the automotive and engineering industries, some companies have ventured into the processing of powders and components required in cutting tools, wear parts and tungsten alloy components for defence applications.

Companies visited by the Defence Minister during his tour of the PM-15 exhibition included:

Fluidtherm

Fluidtherm Technology Pvt Ltd is one India's most prominent PM equipment suppliers, making its products in India and exporting the majority of these all over the world. Established in 1985 in Chennai, over 75 employees now work in developing and manufacturing fully automated and atmosphere controlled industrial furnaces for Powder Metallurgy and thermal processing.

In addition to over 700 installations in India, the company's furnaces have been exported to countries such as Germany, South Korea, China, Spain, Denmark, The Netherlands, Turkey, Egypt, Malaysia, Peru, Iran and Indonesia.

The Managing Director of the company, Gopinath, used a model of a continuous sintering furnace to explain to the Defence Minister how the process works (Fig. 4).

Fig. 4 N Gopinath, Managing Director, Fluidtherm, demonstrating a model of the continuous sintering furnace to India's Defence Minister

Fig. 5 Sidarth Singhal with Dr T R Rama Mohan

Singhal Sintered Private Limited

Headquartered in Kosi Kalan, North India, Singhal Sintered Private Limited (formerly Shivanshu Sintered Products Pvt. Ltd), was established in 2007 and offers a range of products and services from die/tool design to ferrous and non ferrous sintered PM parts. The company has a 23,000 m^2 facility and is ISO/TS 16949:2009 and ISO 9001:2008 certified.

Singhal Sintered Private manufactures a range of products for automotive applications including engine, transmission and shock absorber components as well as bushes and bearings. Its products can be found in commercial and passenger vehicles, motorcycles and tractors. Non-automotive applications include those found in refrigeration compressors, industrial machines and home appliances.

According to Sidarth Singhal, Director of Marketing (Fig. 5), one of the company's aims is to convert the manufacturing of components to the Powder Metallurgy process from conventional routes. The company has annual sales growth rates that

Fig. 7 India's Defence Minister was shown a number of products from SRP Tungsten Pvt Ltd and Electronica Tough Carb Companies

are close to 30%, stated Singhal.

Singhal Sintered Private Limited has a state of art manufacturing unit comprising eight compaction presses ranging from 16 to 300 tonnes, sintering furnaces, steam treatment and a range of supporting utilities. The company was awarded the Godrej Prism Award – Best Localisation Support by Godrej & Boyce Mfg Co. Ltd., along with the Best Powder Metallurgy Product Award by PMAI during PM-13 and a merit certificate at PM-15.

Having regularly exhibited at PMAI events, Singhal considers this to be an important event for a PM part manufacturer. "It also offers visitors the chance to see new applications and identify areas of growth in the Indian PM industry."

Swastik Tungsten Pvt. Ltd.

Swastik Tungsten Pvt. Ltd. is growing business engaged in the extraction of tungsten from tungsten scrap, as well as from ore imported from East Africa. The company has developed its own technology with well established plant, machinery and laboratory facilities. The existing production capacity is 350 MT per annum, which Swastik Tungsten states is projected to reach 1000 MT.

Ajit Arbatti, owner of Swastik Tungsten, commented that the exhibition had provided some very good contacts in the PM field. Many representatives from different companies and different parts of the world had visited their booth to discover more about their products.

During the event Swastik Tungsten was presented with the Best Product (Raw Materials category) Award of PM-15.

Fig. 8 Vinay Choudhary, CEO of Innomet Powders, presented the company's atomised powders and tungsten heavy alloy products to India's Defence Minister

SRP Tungsten Pvt Ltd

SRP Tungsten Pvt Ltd is an SRP Electronica Group Company with a dedicated set up for the manufacturing of tungsten and tungsten carbide powders.

The company has modern production facilities across four sites that underwent capacity expansion in 2011 and 2012. SRP Tungsten uses a solvent extraction process for tungsten, reportedly the first of its kind in India. A range of mining products are also manufactured.

Innomet Powders/Innotung

Padmasree Enterprises is a speciality Powder Metallurgy company in Hyderabad with two divisions, Innomet Powders and InnoTung. The company's CEO, Vinay Choudhary, met with the Defence Minister and presented the company's range of atomised powders and tungsten heavy alloy products (Fig. 8).

Through Innomet Powders the company supplies and manufacturers ferrous and non-ferrous metal and alloy powders. It specialises in manufacturing customised grades of powders containing iron, copper, nickel, tin, zinc and cobalt. Applications include Powder Metallurgy components, diamond tools, welding and brazing, catalysts, surface coatings and many others.

Innotung manufactures tungsten heavy alloy components via the Powder Metallurgy route.

Applications include those found in nuclear radiation shielding, sporting, engineering, aerospace and defence sectors.

Imco Alloys Pvt Ltd

Imco Alloys Pvt Ltd was set up in 2000 by Joydeep Duttagupta and Geeta Duttagupta. As an advanced material science company, it is involved in developing novel metallurgy products to solve various wear problems.

Duttagupta explained to the Defence Minister that the company uses a combination of Powder Metallurgy and ceramic components, with wear resistant castings as replaceable wear surfaces, for large components subjected to extensive wear (Fig. 9). Imco Alloys also supplies hard weld overlays and thermal coatings for various abrasion, erosion, impact, corrosion and cavitation problems in the industry.

The company's 2300 m^2 engineering manufacturing facility in Ambernath, India, includes state of art technology with a six bar vacuum furnace, induction melt furnace offering up to 500 kg single casting, high velocity oxy fuel thermal spray coating, dense arc metal coatings, plasma spraying for various oxides, robotic welding and MIG and TIG welding. Imco Alloys holds an Indian patent on abrasion resistant sintered carbide and another is in the process of being granted. The company has presented various technical papers at international conferences and has won several accreditations and awards.

As an established brand in more then thirteen countries the company supplies various wear combating components used in the sugar, cement, mining and power sectors. Some 40% of its products are exported.

Fig. 9 Joydeep Duttagupta, CEO of Imco Alloys, explained to India's Defence Minister the company's products for wear resistance applications

Fig. 10 The PMAI's President, Gopinath, talked about the status of PM in India and the support required from the government during a group meeting with the country's Defence Minister and representatives from India's PM industry

India's Defence Minister meets PM industrialists

Following his visit to the exhibition Parrikar met with a number of PM industrialists during an inaugural tea. Gopinath, introduced the corporate members and presented a brief report about the trade association and its activities. He also discussed the need for a common R&D centre to be funded by India's Government so that high quality components required for defence can be developed in the country.

During the meeting the Defence Minister was interested to learn of problems being faced by individual members in running their companies.

Fellow of PMAI awards

In addition to the Fellow of PMAI Award presented to India's Defence Minister, both Hans Soderhjelm of Höganäs AB, Sweden, and Luigi Alzati of Imerys Graphite and Carbon, Switzerland, were honoured with this prestigious award (Figs. 11 & 12). The awards were presented by the PMAI's President, N Gopinath, and V Srinivasan, Managing Director of Höganäs India.

Fig. 11 Hans Soderhjelm, Hoganas AB, Sweden, receiving his Fellow PMAI (FPMAI) award from PMAI President N Gopinath (left) and V Srinivasan, MD, Höganäs India (right)

Fig. 12 Luigi Alzati, Imerys Graphte and Carbon, receiving his Fellow PMAI (FPMAI) award from PMAI President N Gopinath (left) and V Srinivasan, MD, Höganäs India (right)

Comprehensive Plenary Sessions at the start of an all topic conference

Powder Metallurgy in the community

The first Plenary Session began following lunch with a presentation from Hans Sojderhjelm, Höganäs AB, Sweden, in which he discussed the prominent role that can be played by PM in a sustainable society.

Sojderhjelm illustrated how PM can make a positive difference as a green technology, helping to make emission free vehicles and cleaner energy generation. The benefits of the PM process in reducing or eliminating waste and the ability to make use of recycled materials were highlighted. He hoped that the PM industry could leave for the younger generation a world as good as we have today.

Changing concepts of innovation

Dr Luigi Alzati, Imerys Graphite and Carbon, Switzerland, discussed the evolution in innovation theories from conceptualisation to modern application in business management.

Although the initial definition of innovation described an 'invention from scratch', Rene Girard (1990) was cited as the first to incorporate the concept of cross-linking of knowledge, questioning the opposition between imitation and innovation. Dr Alzati stated that during the 2000s innovation had become a major focus coupled with corporate entrepreneurship.

Hargadon and Sutton (1997) identified innovation as a sort of 'technology brokering' which occurred when the limitations in knowledge-sharing among people, departments, organisations or industries were solved by the creation of links among these unconnected groups. When the condition for information flow was created, ideas already existing in one industry were imitated, modified, tailored and possibly combined with other ideas and turned out to be new introductions in other industries.

Dr Alzati stated that organisations started to discover successful ways to compete on a global scale by shortening of organisation's life-cycles and speeding up commoditisation. A 'blue ocean strategy' was used which consisted of generating new value propositions and therefore creating new markets. Focus on innovation and corporate entrepreneurship had peaked when the previously undisputed efficacy of Lean Six Sigma methods (LSS) began being questioned. It was argued that LSS and innovation should not be considered as stand-alone systems. Rather, a combination of LSS and innovation was attempted for a systematic innovation approach.

After reviewing the chronological developments in innovation theories, Dr Alzati stated that corporate entrepreneurship studies indicate a signal of the renewed valuation of the human factor in the competitive advantage of businesses. Also, rediscovering innovation as imitation meant acknowledging achievements in one industry as well as technology brokerage from others. It is in line with embracing a clear trend of the present time: more and more the web-based culture leads to the language of community, where knowledge is shared and IT-tools provide networking and therefore provide innovation opportunities previously impossible.

Automated inspection of green parts help in competitiveness

Dr Yusuf Usta of Gazi University, Turkey, spoke on enhancing the competitiveness of PM SMEs by utilising an improved quality assurance tool. The system highlighted was based on the latest digital radiographic process developed during the DIRA-GREEN project.

The main drawback of PM, stated Dr Usta, is that after powder compaction (as a green part), porosity and cracks in the microstructure may be present. This can lead to unreliable mechanical properties that limit the usefulness of this manufacturing technique. Material porosity was assumed not to change during the current sintering process and therefore determination of green part porosity can avoid unnecessary sintering. The DIRA-GREEN project, he said, aimed to develop a non-destructive testing technique using digital radiography, which enables quality assurance of green parts by monitoring compacted material porosity and identifying microscopic cracks (Fig. 13).

The density map for the component, indicating the size and location of defects, can be stored in a database and can facilitate an improvement cycle to optimise Powder Metallurgy mould and die designs, added Dr Usta.

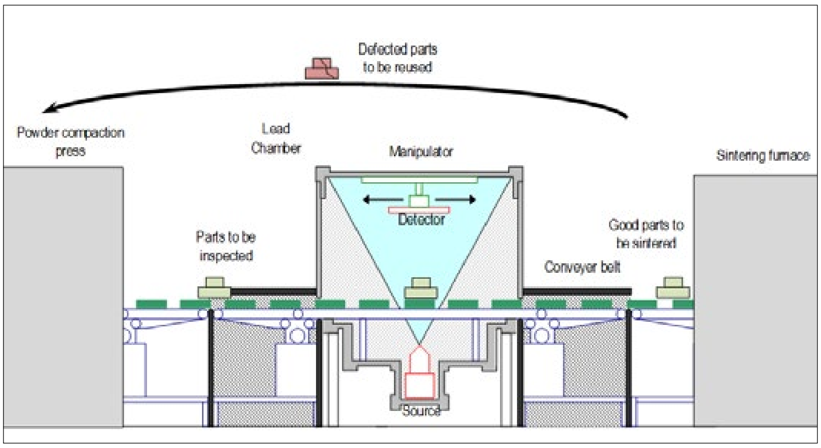


Fig. 13 Schematic showing how the DIRA-GREEN system is used in a PM production line

Academic programmes and research activities at IIT Bombay

Professor N Prabhu, Head of the Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology, Bombay, summarised the activities of the department. He stated that there is a total of 32 faculty members in the department teaching in a four year B. Tech programme, five year B. Tech + M. Tech, dual degree programme, the conventional two year M. Tech. programme and the Doctoral programmes. A total of 231 B. Tech students, 142 Dual Degree students, 159 M. Tech and 61 Ph. D. students have graduated during the last five years.

"The vision for the department is to create an academic ambience that inspires one to seek and address the scientific and technological challenges of the future," stated Professor Prabhu.

The Department of Metallurgical Engineering and Materials Science has made significant contributions in different areas of research such as materials processing, mechanical behaviour and micro structural evolution, corrosion, electronic properties of materials and in the area of computational materials research. In the area of steel making, the department is not only known for its basic research but also for the numerous developmental activities and industry interactions.

The funding for the research programmes has grown in recent times added Professor Prabhu. Substantial levels of funding was obtained from various government agencies and multinational companies such as Applied Materials, TATA Steel, Dow Chemicals, Corning and John Deer to name a few. Companies such as Bharat Forge and Crompton Greaves sponsor students to do post-graduate research.

The total number of research papers published in the past five years in both journals and conferences is around 760. In addition, there have been two books published and five patents obtained in last five years.

Special session reports on developments in engineering ceramics

Engineering of engineering ceramics

Dr Rama Mohan, PM Consultant, Mumbai, opened the PM-15 Special Session on Developments in Engineering Ceramics with a presentation that introduced the subject and illustrated the concepts involved in his paper titled Engineering of Engineering Ceramics.

Depending on the service conditions, he stated, ceramics require special compositions and processing to develop specific crystal structures and microstructures. Typically, the development of high strength and hardness along with good fracture toughness requires micro structural engineering and dispersion toughening with the help of metastable phases. Development of electrical properties requires the addition of proper dopants, control of sintering atmospheres and grain boundary engineering. High temperature strength and corrosion resistance requires the use of highly covalent ceramics processed with suitable secondary phases at grain boundaries. Bio ceramics require biocompatibility with suitable ion exchange to and from the body surroundings.

During his presentation Dr Rama Mohan discussed general approaches to develop specific properties in common engineering ceramics.

Ceramic Injection Moulding

The presentation by Dr Parag Bhargava, Metallurgical Engineering and Materials Science (MEMS), IIT Bombay, discussed various aspects of Ceramic Injection Moulding (CIM). The process, he stated, is generally used for relatively small complex shaped components which are difficult to manufacture by other manufacturing techniques.

Manufacturing of ceramic components through CIM does not require any special grade powders as the particle size of the industrially available ceramic powders is mostly in the sub micrometre range which generally has high sinterability. While all steps in the process are important, the two steps that critically determine the part quality, and often need additional efforts, are the development of feedstocks with appropriate rheology and the process steps for complete removal of organics from the moulded parts without causing any cracks or defects in the parts. All of the basic and technological aspects of CIM were described and insights of research carried out in Ceramic Injection Moulding at the author's lab at IIT Bombay were given.

Ceramic armour materials: Indian experience

Dr S C Sharma of India's Naval Materials Research Laboratory gave an Indian viewpoint of processing and applications of ceramic armour materials. Dr Sharma stated that the choice of armour material for any specific application is a trade off between weight, cost, manufacturing ease and the protection level required. Properties and relative merits and drawbacks of common armour materials were compared. Alumina, silicon carbide, boron carbide and zirconia toughened alumina were identified as the potential materials to meet India's diversified ballistic protection requirements. Work done at NMRL to develop ZTA and boron carbide and composite armour based on ceramics was discussed along with techniques developed for ballistic performance evaluation.

Bioceramics and biocomposites: Current trends and future prospects

A presentation by Dr Deepak K Pattanayak,CSIR-Central Electrochemical Research Institute, Karaikudi, discussed current trends and future prospects in bioceramics and biocomposites. These are a class of materials that can easily integrate in the human body through a bone-like apatite layer when the material comes in contact with body fluids. Most belong to calcium phosphate series although several other bio glasses and glass ceramics are available.

Bioceramics are primarily used in dentistry as fillers in bone and tooth repair due to their limitation of low mechanical strength. However, bioceramics coated orthopaedic and dental devices are gaining popularity as artificial implants, where bone integration is taken care of by these ceramics. Apart from coated implants, polymer-bioceramics or metal-bioceramic composites and porous composite scaffolds are gaining increased applicability in recent biomedical devices, stated Dr Pattanayak. Various types of bioceramics and composites and their applications were reviewed (Fig. 14).

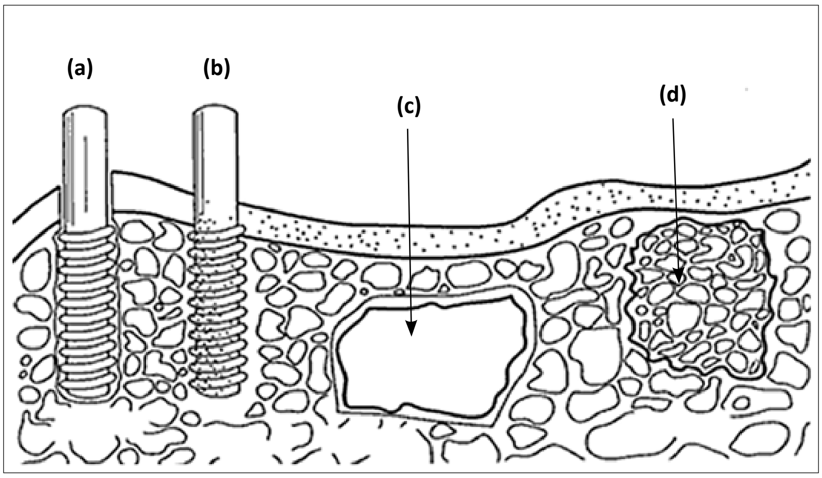


Fig. 14 Classification of bio ceramics according to their bio activity; (a) bio inert, (alumina dental implant), (b) bioactive, hydroxyapatite ($Ca_{10}(PO_4)_6(OH)_2$) coating on a metallic dental implant, (c) surface active, bio glass or A-W glass, (d) bio resorbable tri-calcium phosphate implant [$Ca_3(PO_4)_2$].

Ceramics in energy generation

Ceramics used in energy generation were discussed by Dr Deep Prakash of the Powder Metallurgy Division, Bhabha Atomic Research Centre, Mumbai. Dr Prakash considered the ever increasing demand for energy for sustainable development in the context of the depletion of fossil fuels. Environmental concerns and global warming, for example, pose challenges as well as provide impetus for harnessing new energy technologies, he stated. Nuclear reactors based on fission as well as fusion, fuel cells, thermoelectric and Alkali Metal Thermal Electric Converters (AMTEC) etc, offer tremendous potential for energy solutions.

Many of these energy generation technologies involve ceramics and PM techniques. A number of existing and emerging energy generation technologies with an emphasis on the role of ceramics and particulate materials were presented.

Fig. 15 Dr Amol Gokhale, Director DMRL, presenting his R V Tamhankar memorial lecture

Fig. 16 Dr J K Chakravarthy gave the P R Roy memorial lecture

Fig. 17 Bijoy Sarma, presented the S L N Acharyulu memorial lecture

Memorial lectures focus on defence and nuclear

R V Tamhankar Memorial Lecture

Dr Amol A Gokhale, Director, Defence Metallurgical Research Laboratory (DMRL), Hyderabad, gave a presentation on Powder Processed Materials for Defence Applications in the R V Tamhanker Memorial Lecture (Fig. 15).

Many special materials with applications in strategic sectors rely on Powder Metallurgy as the processing technique. Dr Gokhale outlined efforts made at the DMRL in the development of tungsten heavy alloys for anti tank kinetic energy penetrators, samarium cobalt permanent magnets for accelerometers and BLDC motors, ZrB_2-SiC composites for ultra high temperature hypersonic applications and certain special components based on functionally graded and heterogeneous compositions. These materials and components were produced using techniques such as Cold Isostatic Pressing and liquid phase sintering, Hot Isostatic Pressing, vacuum hot pressing and laser engineered net shaping.

Several components are being developed for battle tanks, light and medium combat aircrafts, submarines and aircraft carriers, besides for ammunition and propellants, added Dr Gokhale.

P R Roy Memorial Lecture

The P R Roy Memorial Lecture was presented by Dr J K Chakravartty, Materials Group, Bhabha Atomic Research Centre, Mumbai, who discussed the importance of dynamic recrystallisation in thermo-mechanical processing of materials (Fig. 16).

Typically, this becomes important when the material is deformed in the hot condition, in single or multiple steps, with the aim of obtaining a desired microstructure. Dr Chakravartty discussed the processing and microstructural evolution of various hot deformed metals and alloys such as Zr-1 Nb, Zr-2.5Nb, Zircaloyed cobalt (in both the wrought and sintered condition), SS304 and 316, natural uranium and U-9wt%Mo alloy, Nb, Nb-1 Zr and Nb-1Zr-0.1 C alloys, V and V-4Cr-4Ti alloy, and Mo-Ti-Zr alloy.

S L N Acharyulu Memorial Lecture

The final memorial lecture was presented by Bijoy Sarma, Institute of Defence Scientists and Technologists, Hyderabad, who discussed work done by the group led by the late SLN Acharylu at DMRL regarding Powder Metallurgy components in ordnance (Fig. 17).

In order to achieve successful technological performance, support of the material at its peak property level is a must, stated Sarma. Often, these new performance challenges are being met by processing techniques such as PM to bring out the best in materials performance. PM processing gives controllable microstructures even at resolution levels of nanometric order.

Powder material techniques have matured and acquired exclusive status, he stated, albeit with the high cost associated with small production levels. Ordnance is somewhat different from commonplace engineering use in that a very high degree of reliability is demanded (in often short duration or one-time use) from materials and the qualification procedure is therefore more elaborate, all of which gets included in the processing cost.

Some examples of extreme performance regimes were discussed with processing solutions that are practised successfully in spite of certain occasions of metallurgical incompatibility. Metal Matrix Composites (MMCs) have provided many solutions to high performance applications, added Sarma.

Processing of high purity and ultrafine powders, full densification, through warm compaction, liquid phase and pressure assisted sintering, followed by thermo mechanical treatments and surface engineering as needed to meet the service conditions were discussed as relevant to military use.

Fig. 18 The winner of Grand PMAI Student Award was R Shashanka of the National Institute of Technology Rourkela (centre), seen here with N Gopinath, PMAI President, and Prof. Yusuf Usta, Gazi University

Further awards at PM-15

For this year's event the Powder Metallurgy Association of India greatly increased the number of awards it presents to students, scientists and exhibiting companies. An expert committee evaluated the submissions and the awards were presented during the conference.

Grand PMAI Student Award

The recipient of the Grand PMAI Student Award receives an all expenses paid trip to an overseas international Powder Metallurgy conference or exhibition. The destination for this year's award was announced as being the PM 2015 Exhibition and Conference in Shanghai, China (April 27-29, 2015). This year the award was supplemented by a generous donation from Stefania and Luigi Alzati to include expenses to also attend the PowderMet 2015 Conference in San Diego, USA (May 17-20, 2015).

The winner was announced as R Shashanka of the National Institute of Technology Rourkela, for a paper studying the effect of Y_2O_3 on non-lubricated sliding wear resistance of duplex stainless steel.

In this paper the non-lubricated sliding wear resistance of nano Y_2O_3, (1 wt% Y_2O_3) dispersed duplex 5 (Fe-18Cr-13Ni) stainless steel was studied. The cold compacted pellets were sintered at 1000, 1200 and 1400°C in tubular furnace using argon atmosphere for one hour. It was found that both hardness and density increased with increase in temperature. Microhardness values of duplex and yttria dispersed duplex stainless steels went on increasing from 257 to 550 HV and from 332 to 594 HV respectively with increase in sintering temperature from 1000 to 1400°C.

Density increased from 66 to 90% in the case of duplex stainless steel and 70 to 92% in the case of yttria dispersed duplex stainless steel when sintered at 1000 to 1400°C respectively. XRD analysis showed the domination of more intense austenite phase at higher temperatures. Ferrite phase decreased with increase in sintering temperature from 1000 to 1400°C respectively.

The wear properties were studied by using a ball on a plate wear-testing machine with diamond indenter. Wear depth of duplex stainless steel decreased from 28 to 16 μm with increase in sintering temperature from 1000 to 1400°C. In the case of yttria dispersed duplex stainless steel the wear depth decreased from 7 to 3 μm, with increase in sintering temperature. Wear volume of both the stainless steel samples were calculated by using the Archard equation. The volume of wear debris produced decreased with the dispersion of nano Y_2O_3 and increasing sintering temperature.

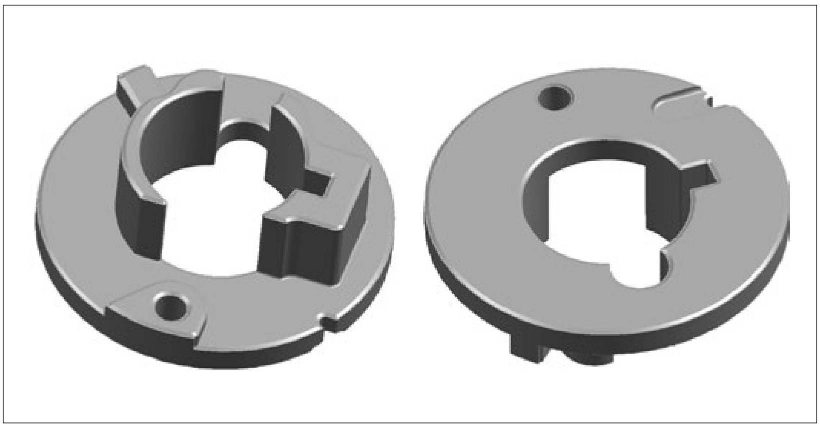


Fig. 19 GKN Sinter Metals Pvt. Ltd received the Best PM Part 2015 award for their base plate component used in a motorcycle engine camshaft assembly

The PMAI Guiding Hand Award for Faculty

An award was presented to the principal lecturer of the winner of the Grand PMAI Student Award. As Sashanka's lecturer, Dr Debasis Chaira, Assistant Professor at the National Institute of Technology Rourkela, received the prize.

G S Tendolkar Award

Deepak Kumar Misra received the G S Tendolkar Award for the paper 'Development of Invar-Silver Composite for MIC Carrier Plate of

Satellites' authored by D K Mishra, T T Saravanan, G F Khanra, S C Sharma and K M George of Vikram Sarabhai Space Centre, ISRO, Trivandrum.

Invar - Silver composites have great potential for use as a carrier plate for Microwave Integrated Circuits (MIC) used in satellites due to high thermal conductivity and optimum coefficient of thermal expansion (CTE). These are required to dissipate the heat which is generated from the microcircuits. The optimum coefficient of thermal expansion of the composite has to match with the CTE of the ceramic substrate (such as Al_20_3) bearing the carrier plate to prevent the failure of the solder due to the thermal stresses.

Invar based silver composites were developed through a Powder Metallurgy route having 20- 25 wt% silver and a balance ofh Invar. High purity Invar powders were compacted at different compaction pressures and sintered at 1150- 1250°C under hydrogen atmosphere to achieve a controlled porosity in the sintered skeleton. The Invar skeleton subsequently was infiltrated with silver through capillary action at a temperature above the melting point of silver. The composite obtained was characterised through physical, thermal and mechanical property evaluation. Thermal conductivity of 48- 55 W1m.K and CTE in the range of 5.8- 6.2 pprn/ K were obtained. Scanning Electron Microscope (SEM) microstructures revealed the homogenous distribution of silver in the composite.

The PMAI Award for a Young Promising Professional

The award and a certificate for the best paper of industrial relevance was given to Dr Deepak K Pattanayak of CSIR-Central Electrochemical Research Institute, Karaikudi, India.

Best Powder Metallurgy Part Award 2015

The winner of the Best PM Part 2015 was presented to GKN Sinter Metals Pvt. Ltd., India. The award recognised the ability of GKN Sinter Metals to meet a variety of technical challenges in the production of a complex base plate component used in a motorcycle engine camshaft assembly (Fig. 19).

Best Powder Metallurgy Product (Raw Material) Award 2015

This award was given to Swastik Tungsten Pvt. Ltd. for its development of tungsten powder for strategic applications.

Certificates of Merit 2015

A Certificate of Merit was presented to Singhal Sintered Pvt. Ltd. for the conversion of a previously forged part into a PM clutch head for an automatic slack adjuster

Speciality Sintered Products Pvt. Ltd. also received a Certificate of Merit for the development and processing of a large PM part. The lever component is used in automotive transmissions and the award recognised the programming of the press and the pressing technique employed for obtaining close dimensional tolerances.

Author

Prof Ramamohan Tallapragada
PM Consultant,
Mumbai,
India.
Email: ramamohant@gmail.com

Gas alloying of low alloy Powder Metallurgy parts for improved mechanical properties

Pownite is a new (patent applied) post sintering gas alloying process developed at Fluidtherm Technology's Research and Development Centre in India. The process improves the mechanical properties of low alloy sintered parts by controlled nitrogen diffusion in the metal matrix of the parts at a temperature between 590°C and 700°C. In this article N Gopinath and V Raghunathan of Fluidtherm Technology describe the process and provide examples of its application.

The traditional method of improving the mechanical properties of PM parts is to subject them to well documented heat treatment processes after the parts have been sintered and cooled. This method involves additional manufacturing steps and can result in undesirable side effects such as distortion and pollution which increase the manufacturing cost.

A process for improving the hardness and other mechanical properties of PM parts has been developed by Fluidtherm. The Pownite process involves the alloying of parts with nitrogen in a manner that causes the formation of an austenitic phase in the metal matrix in addition to the formation of hard transformation products and interstitial nitrogen throughout the section thickness of the parts, or to a substantial depth below the surface of the parts. The level depends on the process parameters employed such as temperature, time at temperature, composition of the sintering atmosphere gas mixture and the properties of the parts such as density, thickness and alloying elements.

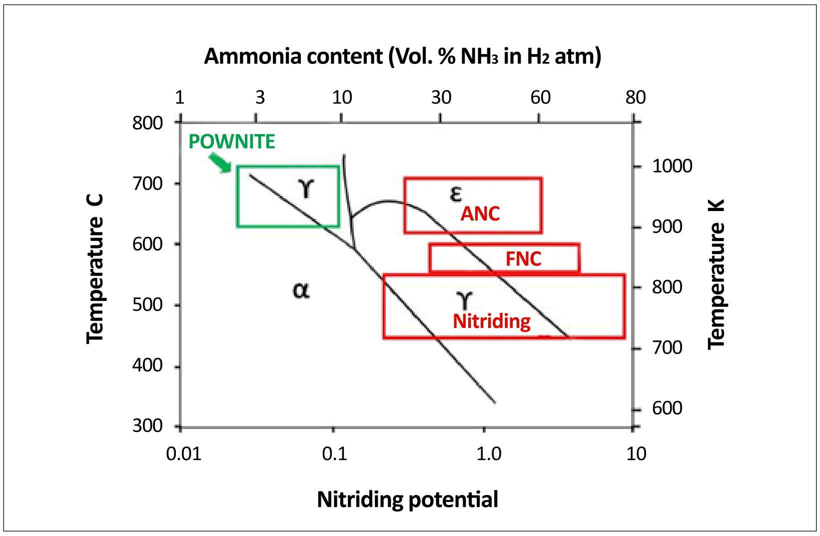


Fig. 1 The Pownite process positioned in a Lehrer diagram

The resulting structure is predominantly nitrogen rich austenite which enhances the hardness and strength mechanical property of processed parts. An optional aging, typically above 350°C, converts the bulk of the austenitic phase to hard transformation such as bainite and martensite.

This process differs from nitriding-type processes in that it is not a surface hardening technique which relies on the formation of surface iron nitrides. The positioning of Pownite as well as conventional gas Nitriding, Ferritic (FNC) and Austenitic Nitrocarburising (ANC) are shown on the Lehrer diagram in Fig. 1.

Dimensions (mm)	18.00 OD, 12.00 ID & 18.6 Long			
Material	Fe-2% Cu-C			
Material code	A	B	C	D
Carbon %	0.5	0.5	0.8	0.9
Density (g/cc)	6.8	7.2	6.8	7.2

Table 1 Details of experimental bushes

Material code (see table 1)	A	B	C	D
As sintered	535.05	616.54	675.58	745.40
Oil quenched and tempered	923.30	917.31	942.62	1025.87
Pownited				
Experiment N5	829.64	693.33	531.32	601.15
Experiment N9	666.85	664.89	686.47	680.48

Table 2 Radial crushing strength (Mpa) of Pownited bushes compared to 'as sintered' and quench and tempered bushes

Testing of Pownite: Bushes

Experiments on bushes described in Table 1 were undertaken in a purpose built pusher furnace in order to characterise the process. Several processes were conducted, of which two, N5 and N9, are reported in this article. The process cycles are shown in Figs. 2 and 3. In both cases, parts were cooled in the process atmosphere. The alphanumeric references L0, L2 and L4 refer to the atmosphere nitrogen potential on a scale of 0 to 4.

Radial crushing strength

Pownite processed bushes were tested in an universal testing machine to arrive at the radial crushing strength (Table 2) and compared with as sintered bushes as well bushes that had been oil quenched and tempered, all from the same production run.

Surface structure

Metallographic examination of the N5 sample can be seen in Fig. 4 and the N9 sample is shown in Fig. 5.

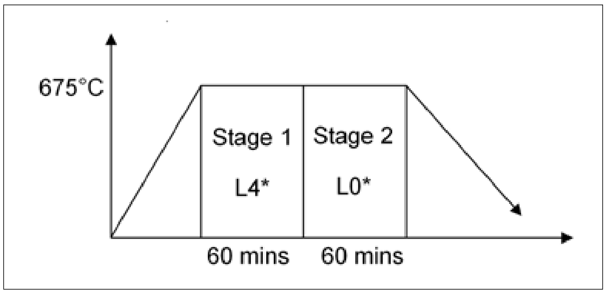


Fig. 2 Experimental N5 process cycle

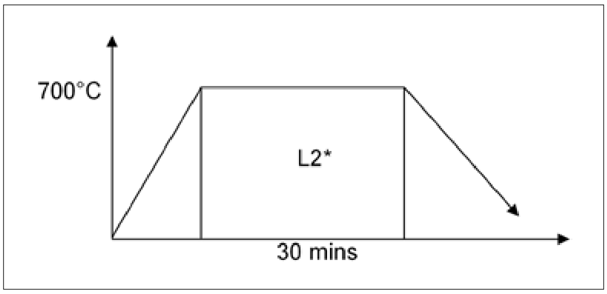


Fig. 3 Experimental N9 process cycle

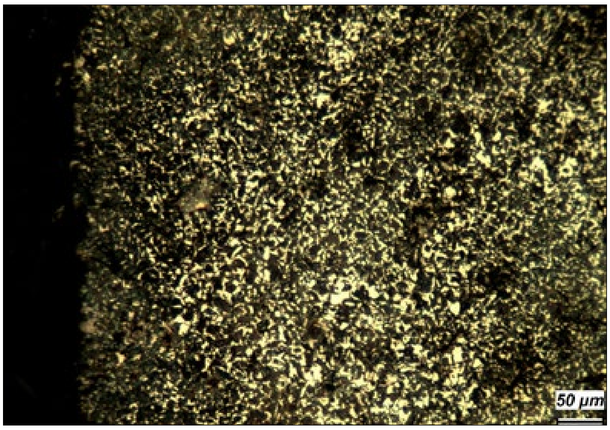


Fig. 4 The surface structure of an N5 Pownited sample shows bainite with ferrite and an absence of iron nitrides

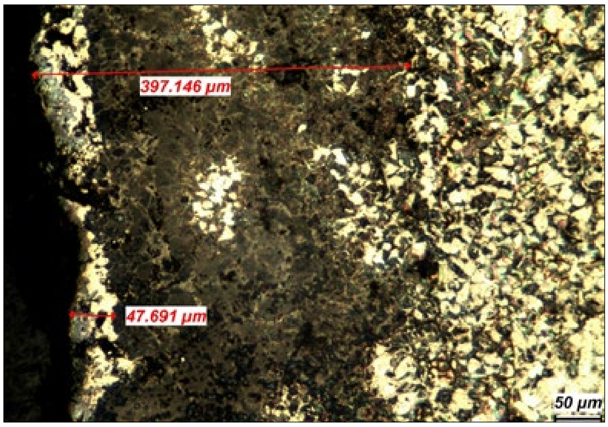


Fig. 5 Surface structure of an N9 Pownited sample shows a shallow layer of iron nitride with a substrate of bainite

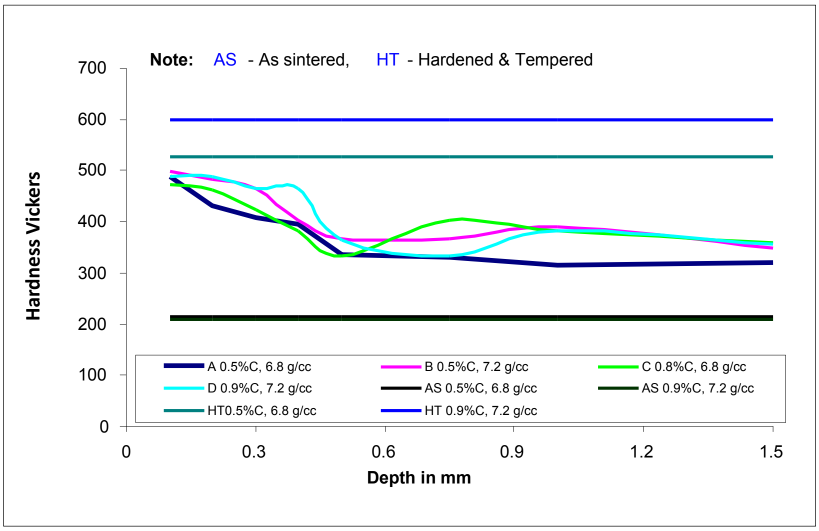


Fig. 6 Hardness profile of Through Pownited bushes (experiment N5)

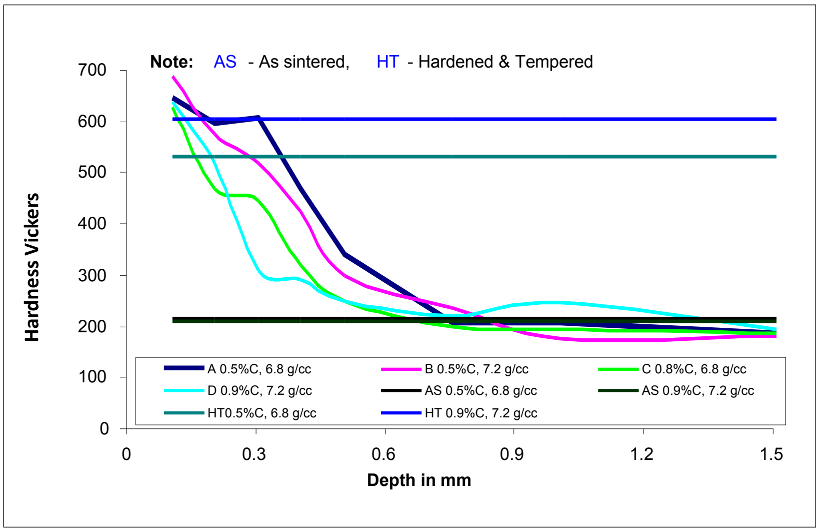


Fig. 7 Hardness profile of Case Pownited bushes (experiment N9)

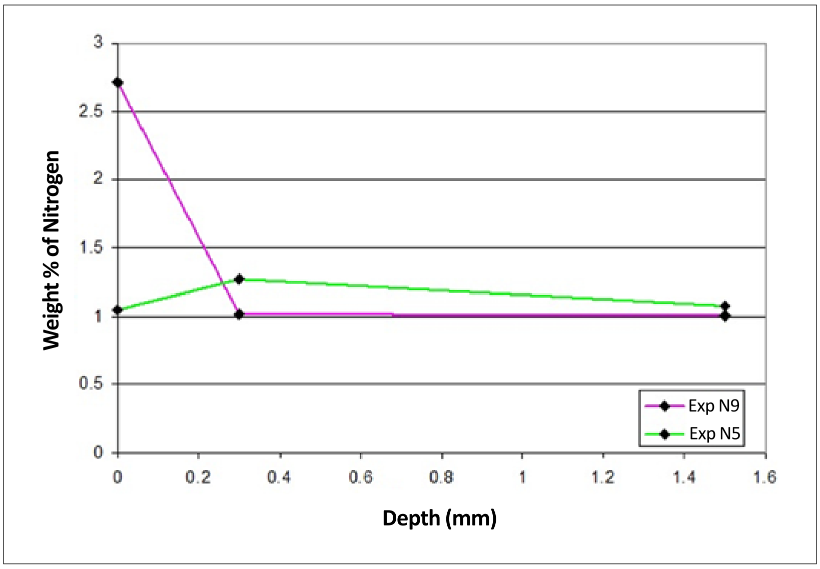


Fig. 8 Nitrogen weight percentage of sample bushes N5 and N9

Hardness

Hardness was measured across the cross section of Pownite processed bushes to check the surface to core variation and this was compared with as sintered and quench and tempered bushes. The hardness profile of Through Pownited bushes sample N5 can be seen in Fig. 6. The hardness profile of Case Pownited bushes sample N9 is shown in Fig. 7.

Nitrogen content

The nitrogen content was analysed by SEM – EDX from surface to core (Fig. 8). Bushes processed in experiment N5 had hard transformation products throughout the section thickness without any surface nitride layer. The core hardness was higher than in the as sintered bushes but lower than the quench and tempered control samples. Bushes in experiments N9 were processed for higher surface nitrogen concentration (for improved wear resistance) and the resulting hardness profile shows higher surface hardness than the quench and tempered parts.

Toughness at varying density and aging temperatures

Another batch of sintered bushes (Fig. 9) with density of 6.4, 6.8 and 7 g/cm^3 and composition of Fe + 0.5%C+ 2%Cu were Pownited with process conditions shown in Fig. 10. The samples were aged at different temperatures to study the resulting toughness. The results are compared with quench and tempered bushes in Figs. 11 and 12.

It is seen that the toughness of the Pownited bushes is higher than the as sintered bushes for all studied densities. The toughness of Pownited bushes that were aged at a higher temperature is higher than that of the quenched and tempered bushes.

Consequently, a case exists for a detailed evaluation of the possibility of using Pownited bushes of a lower section thickness in place of thicker conventional bushes for savings in material and energy.

Fig. 9 Experimental sintered bush with OD of 28.8 mm, ID of 19.5 mm and 26.5 mm long

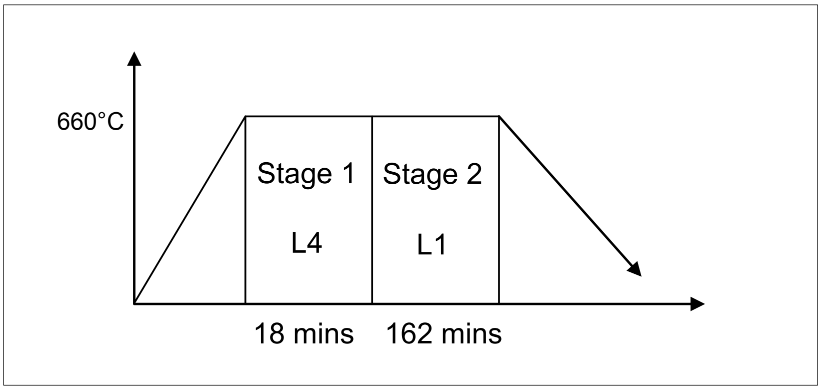


Fig. 10 Experimental process cycle used in toughness testing

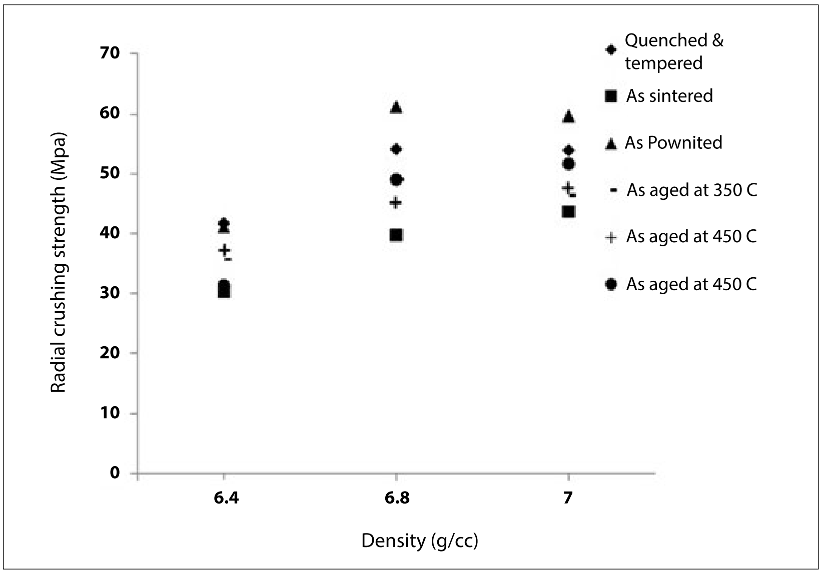


Fig. 11 Radial crushing strength of Pownited and aged, quench and tempered and as sintered bushes

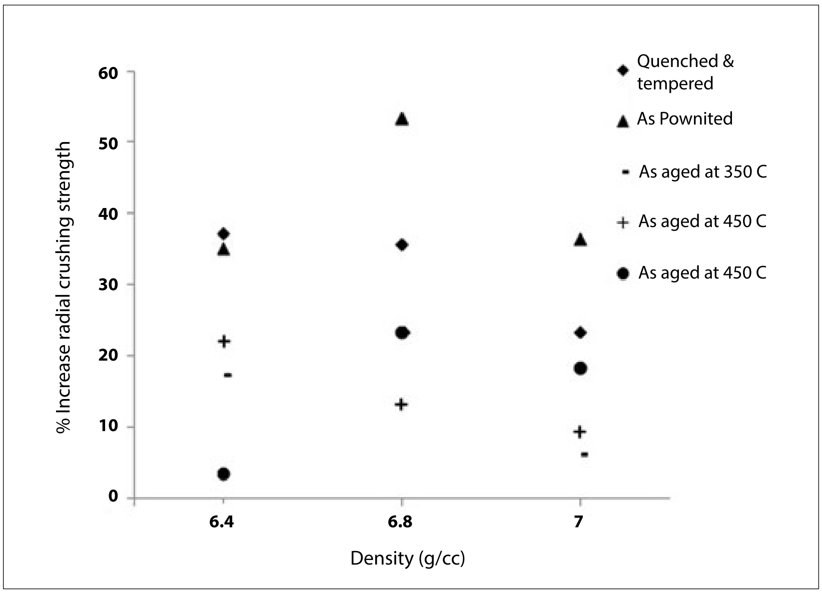


Fig. 12 Percentage change of the radial crushing strength of Pownited and aged bushes compared to as sintered and quench and tempered bushes

Testing of Pownite: Sprockets

A selection of motorcycle sprockets (Fig. 13) composed of Fe + 0.5% C + 2.5% Cu Fe with a density of 6.8 g/cm^3, were Pownited and aged at different temperatures and compared to conventionally carbonitrided, quenched and tempered sprockets (Table 3). The microstructure of the Pownited parts, after aging at 450°C, was predominantly bainite at the surface with ferrite, pearlite and bainite at the core (Fig. 14).

The hardness profiles created by the two process variants were also compared as can be seen in Fig. 15.

Conclusions

It can be stated that gas alloying, when properly executed, enhances the mechanical properties of unalloyed PM parts. The strengthening is due to the formation of nitrogen-rich austenite, the presence of interstitial nitrogen and, in some cases, the conversion of austenite to bainite when aged.

In addition to the overall strengthening of PM parts, the process parameters can be modified to provide a surface layer of iron nitrides for improved properties. Also, the radial crushing strength of Pownited medium carbon bushes is seen to be distinctly higher than the as sintered bushes, regardless of part density.

Fig. 13 The sample motorcycle sprocket

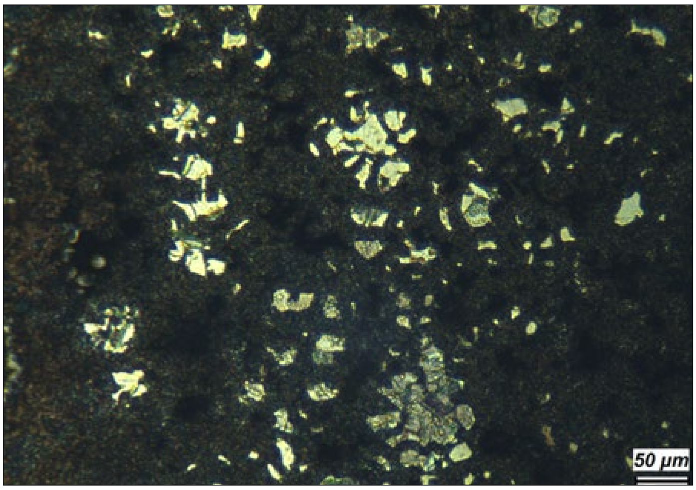


Fig. 14 The sprocket displays a predominantly bainite surface

The increase in strength of Pownited PM parts raises the possibility of a reduction in section thickness and consequent material and energy saving.

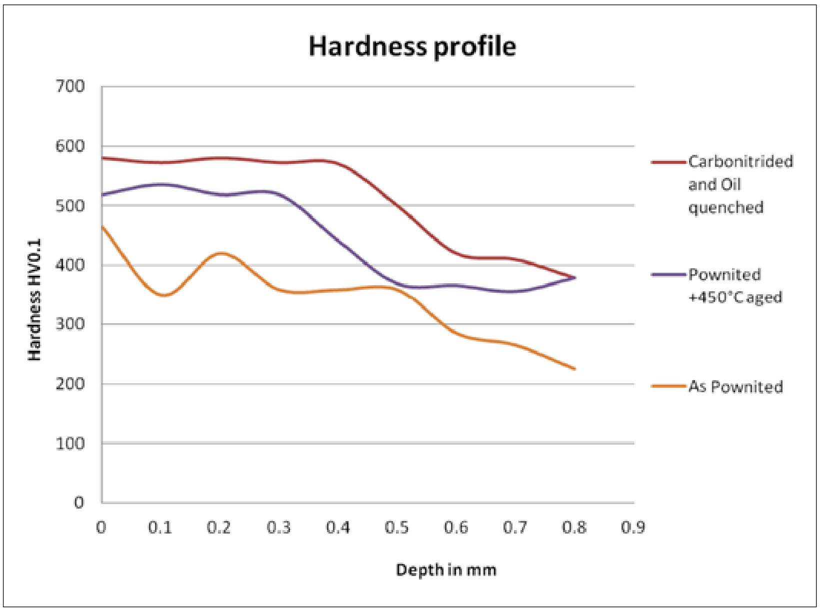


Fig. 15 Hardness profile of Pownited and carbonitrided sprockets

Property	Drawing specifications	Obtained after carbonitriding	Obtained after Pownite processing and ageing at 450°C
Surface Hardness HV0.5	450 Min.	570	543
Case Depth at a cut-off depth at 450 HV0.5	0.2 to 0.5 mm	0.55 mm	0.38 mm
Core hardness HV0.5	450 Max.	360	225

Table 3 Comparison of properties, Pownited and carbonitrided sprockets

References

[1] Howard A Ferguson, Heat Treating of Powder Metallurgy Steels, ASM Handbook Volume 4. pp 229 - 236.
[2] David Pye, Practical Nitriding and Ferritic Nitrocarburizing (#06950G), ASM Handbook Vol 4, 2003, pp 430 - 433.
[3] N Gopinath and V Raghunathan, A New Post-Sintering Process to Improve the Mechanical Properties of PM parts by Gas Alloying, PM 2014 World Congress, Orlando, MPIF.

Author

N Gopinath and V Raghunathan,
Fluidtherm Technology P. Ltd.,
SP132, III Main Road,
Ambattur Industrial Estate,
Chennai 600 058,
India
Tel: +91 44 26357390
Email: info@fluidtherm.com
www.fluidtherm.com

PM INDUSTRY EVENTS

2015

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

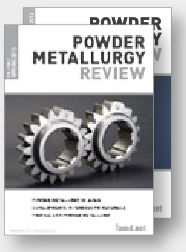
Euro PM2015
October 4-7,
Reims, France
www.epma.com

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

ADVERTISING

To discuss advertising in *Powder Metallurgy Review* contact:
Jon Craxford,
Advertising Sales Director
Tel: +44 207 1939 749
jon@inovar-communications.com



POWDER METALLURGY REVIEW

Advertisers' index

DORST TECHNOLOGIES

Production Technologies for Challenging Applications

Machine, Tooling and Powder - when this fits together, the result is such products.

Dorst has the answer.

WE BRING CERAMICS AND METAL POWDER INTO SHAPE