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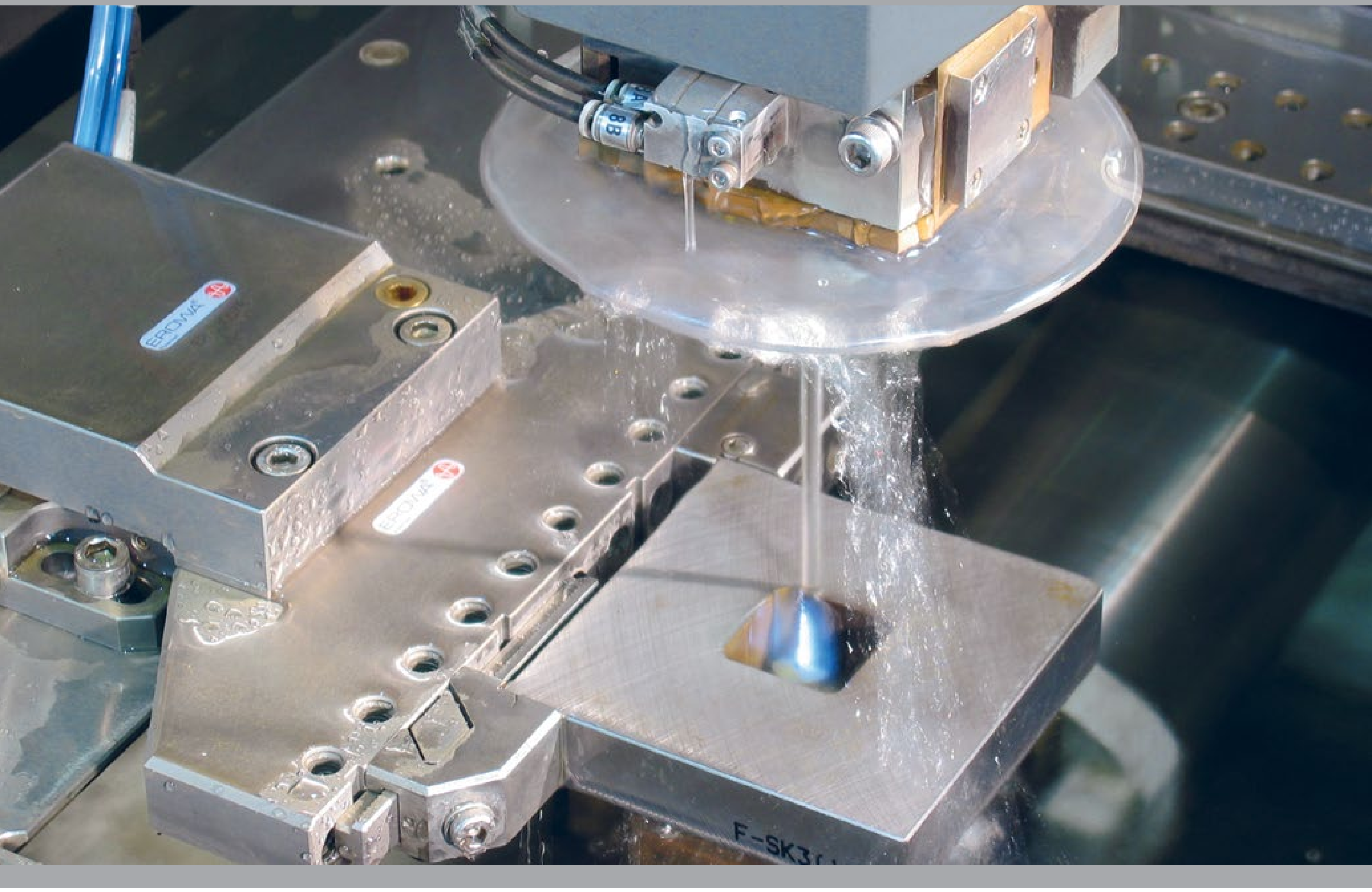
POWDER METALLURGY REVIEW



PM TOOLING DESIGN AND OPTIMISATION

POWDER METALLURGY GEARS

HAGEN SYMPOSIUM 2013

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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.

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POWDER METALLURGY REVIEW

Optimism for growth in the Powder Metallurgy industry

The global automotive industry is expected to generate 85 million unit sales in 2014, a 4% increase on last year. There are predictions that by 2018 this total will have topped 100 million units. This is good news for the Powder Metallurgy industry and offers reason for much optimism for those who supply the automotive sector. However, the PM industry cannot rely solely on volume increases in the automotive sector for growth in business. New PM applications and the conversion of components produced by competing processes to PM also offers considerable growth potential.

One such opportunity lies in applying the benefits of PM technology to the production of automotive transmission gears. A detailed report in this issue of *Powder Metallurgy Review* highlights the current status of PM automotive transmission gear design and outlines what is required to succeed in this potentially very lucrative sector (page 45).

Also of great potential for the PM industry is the development of sintered thermoelectric alloys for energy harvesting applications. These alloys can, for example, help power automotive electrical systems and improve fuel efficiency. We take a look at some of the ongoing developments using PM technology to produce a new generation of sintered thermoelectric alloys (page 55).

To further improve efficiency in the PM process the correct design and optimisation of tooling is a major factor. We present in a special report the various ways in which PM companies can optimise this process and minimise the risk of failures (page 33).

Paul Whittaker
Editor, *Powder Metallurgy Review*

Cover image
EROWA's Wire-EDM workpiece clamping system used in the production of tooling

POWDER METALLURGY REVIEW

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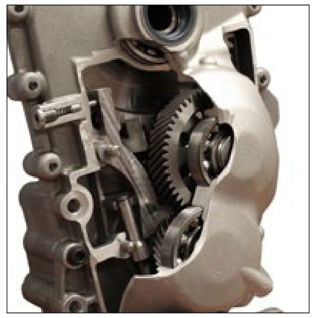

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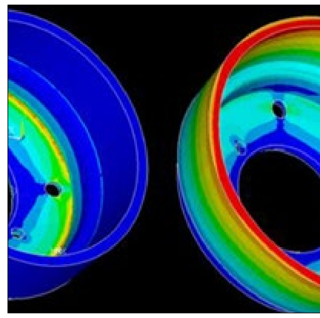

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regular features

industry news

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

Alpha Sintered Metals sold to O2 investment partners and management team

Alpha Sintered Metals, Inc., based in Ridgway, Pennsylvania, USA, has announced that O2 Investment Partners, LLC, a private equity firm located in Bloomfield Hills, Michigan, USA, and Alpha's existing management team have acquired the business from Cyprium Partners. Full terms of the deal were not disclosed.

JoAnne Ryan, President & CEO of Alpha Sintered Metals stated, "Our partnership with O2, an organisation which shares our values and strategic vision, provides access to the resources necessary for Alpha Sintered Metals to continue its growth trajectory with existing core products and customers while allowing for expansion into additional targeted niche markets and technologies and growth through strategic acquisition."

Founded in 1967, Alpha Sintered Metals, Inc. is a supplier of high-strength precision PM gears and fully-assembled modular camshafts, with capacity to process high-density stainless steels for automotive, heavy duty, and off-highway exhaust systems. The company employs 265 people with manufacturing locations in Ridgway, Pennsylvania, USA and Yizheng, China.

Jay Hansen, President and Managing Partner of O2 Investment Partners, stated, "We are very pleased with our investment in Alpha Sintered Metals and its employees. The vision that JoAnne and the management team have developed for this business is truly exciting and we look forward to supporting the Alpha team in achieving the plan."

"We also view Alpha as an exciting platform for developing or acquiring additional businesses in the powdered metal component sectors and are actively seeking add-on acquisitions," added Hansen.

www.alphasintered.com

Alpha manufactures a wide range of PM components (Courtesy Alpha Sintered Products)

Royal Metal Powders acquires Horsehead copper powder business

According to the Blount Partnership Chamber of Commerce, American Chemet located in Illinois, USA, has announced the purchase of the Horsehead Corporation copper based air atomising business, located in Palmerton, PA. The assets and production of the Horsehead business will be relocated to Royal Metal Powders, Inc., a subsidiary of American Chemet located in Maryville, TN.

Mike Lutheran, President of Royal Metal Powders, stated that this acquisition allows Royal to increase production and sales at Royal's existing air atomisation plant located in Maryville, TN. Royal currently produces copper and copper based alloy products that parallel the family of products produced by Horsehead Corporation.

www.chemet.com/royal

Höganäs opens new mixing plant in Korea

Höganäs AB has announced the opening of a new mixing plant in Busan, Korea. The new facility has annual capacity of 20,000 tons and is expected to make sales of SEK 400 million (€45 million) in the Korean market during 2014.

The mixing plant is Höganäs' most modern to-date. It has been built to minimise the distance from warehousing to mixing, packing and finally delivery. The facility features a well-equipped test laboratory and has already received its first ISO 9000 certification.

Alrik Danielson, CEO and President of Höganäs AB, stated in an interview with the Korean Economic Daily, "Up until now, Höganäs Korea has mainly engaged in importing metal powders for customers such as Hyundai Motor and Kia Motors and their partner firms. Once the Busan plant is up and running, we will be able to customise our products to the needs of customers. The time it takes to deliver goods will also be reduced to a week from as much as three months."

Opening of Höganäs' new metal powder mixing plant in Busan

"We will also open markets in Southeast Asia. As we secured large tracts of land for the plant, we will consider capacity expansion sooner or later," added Danielson. "Busan will be the centrepiece of our Asian strategy. After the demand from Japan, Taiwan, and other Asian markets rises, we will set out to expand the plant in Busan within three years."

The inauguration began with ceremonial tree planting and a ribbon cutting ceremony, followed by speeches from the Swedish Ambassador to Korea, the Vice Mayor of Busan and the Chairman of the Korea PM Association.

www.hoganas.com

Hitachi Chemical to increase Powder Metallurgy production in Indonesia

Hitachi Chemical Co., Ltd. has announced that it will increase production capacity at its manufacturing subsidiary in Indonesia in order to meet increasing local demand for PM products. Operations will begin in spring 2015 and Hitachi Chemical is aiming to increase sales for PM products for automobiles and motorcycles in Indonesia by 50%.

Indonesia has been exhibiting continued healthy growth in the motorcycle market. Meanwhile, with the large increase in demand for automobiles predicted to result from the government's implementation of the Low Cost Green Car Policy in 2013, automobile manufacturers and auto parts manufacturers are moving to increase production capacity and work to procure parts locally.

Hitachi Chemical Indonesia has been producing powder metal products mainly for motorcycles in Indonesia since 2012. However, the decision was made to increase its production lines within the premises of its already-existing plant in order to incorporate increasing demand with the growth seen in the automobile market.

Hitachi Chemical Group's PM products bases have spread to Japan, the US, China, Singapore, Thailand, Indonesia and India. "We are working to expand our product supply network worldwide to meet customer needs and to reinforce and increase our powder metal product business," stated Hitachi.

www.hitachi-chem.co.jp

Federal-Mogul agrees to purchase significant portion of Honeywell Friction Business

Federal-Mogul Corporation has announced that its European subsidiaries entered into a definitive purchase agreement to acquire certain business assets of the Honeywell automotive and industrial brake friction business, including two recently established manufacturing facilities in China and Romania. Honeywell Friction Material business is headquartered in Glinde, Germany and employs over 2,000 people globally.

"This acquisition accelerates Federal-Mogul's long-term strategy to strengthen its core product lines, including its global friction portfolio for both original equipment and aftermarket customers. We believe this transaction will generate significant synergies which will create substantial value for all stakeholders," stated Carl C Icahn, Chairman of the Board of Federal-Mogul.

"Honeywell's recognised braking technology and its restructured manufacturing footprint make the acquisition a solid addition to our existing global friction business," stated Kevin Freeland, CEO, Federal-Mogul Vehicle Components. "We expect to combine the Federal-Mogul and Honeywell brake businesses to realise significant synergies in all elements of the business. Our customers in all segments and regions will benefit from the transaction as we will be able to provide them with the best of both companies."

Federal-Mogul today supplies an extensive line of automotive and heavy-duty original equipment and aftermarket brake components. Federal-Mogul is among the first brake friction companies to offer low- and zero-copper brake formulations for original equipment customers, and recently launched low copper brake pads in the aftermarket as well.

www.federalmogul.com

Innovative water pumps enable high processing rates at major South Korean steel manufacturer's water atomising project

Hughes Pumps, based in West Sussex, UK, has recently supplied three HPS5000 high-pressure pump sets to one of the world's leading steel manufacturers based in South Korea as part of a water atomising project, a process that has the potential to handle huge throughputs of metal on a single melt stream, potentially delivering increasing performance levels and low operating costs.

In the water atomising process, molten metal is poured through a high-pressure water spray ring fitted with high-pressure fanjet nozzles that atomises the molten metal into metal powder, which is typically used for sintering engineering components.

Water atomisation was chosen because it produces irregular shaped particles as well as allowing large processing rates of up to around 1000 kg (2200 lb) per minute. This irregular shape offers the benefits of a much larger surface area, which when used in refining applications allows a greater surface area for chemical attack. Powder Metallurgy (PM) parts produced by pressing and sintering rely upon the irregular shapes to produce the compressibility and locking nature that holds the parts in their green shape - a certain strength that allows easier handling and sintering.

The Hughes Pump's system comprised two duty and one standby pump, each with a performance of 750 lpm at 140 bar (200 gpm at 2,000 psi) giving a combined performance of 1500 lpm at 140 bar (400 gpm at 2,000 psi). Each pump was driven by a 200 kW (270 hp) electric motor.

The HPS5000 pumps were chosen for their quintuplex (5 cylinder) design, which produces a much smoother output than triplex (3 cylinder) pumps. The pumps were also fitted with discharge pulsation dampers to smooth the output even further. This was a prerequisite due to the extensive run of rigid stainless steel discharge pipework installed on the system.

The pumps incorporated pneumatic dump/pressure regulating valves that were controlled by the central PLC to enable remote on/off load control and pressure adjustment.

As with all Hughes Pump models, the HPS5000 pump is pressure lubricated and oil cooled as standard. As the process water was to be re-cycled and therefore subject to heat rise, increased size oil coolers were fitted to the pumps to allow for the incoming water supply at 40°C (104°F).

www.hughes-pumps.co.uk

Hilti posts higher 2013 sales despite difficult European market conditions

Figures published by Hilti Group, headquartered in Schaan, Liechtenstein, show an overall increase in sales during 2013 of 4.5% compared to the previous year (for sales in local currencies). Expressed in Swiss Francs this equates to a sales increase of 3.2%, to a total of CHF 4,340 million.

At 3.2%, sales growth for the whole of 2013 was in the expected lower single-digit range, stated the group. Total sales for Europe in local currencies were down 1.1% from 2012. While the Hilti Group continued to grow in Central and Northern Europe, conditions in Southern Europe remained difficult.

In North America, sales were up 2.8%. Sales in Emerging Markets continued to grow at a high pace, with the regions of Eastern Europe / Middle East / Africa (+14.3%), Asia/Pacific (+17.3%) and Latin America (+17.9%) posting double-digit growth rates. Converting to Swiss Francs, however, sales growth in these regions was severely impacted by strongly negative exchange rate effects.

www.hilti.com

Arcam acquires metal powder manufacturer AP&C from Raymor Industries

AP&C's plasma atomisation production unit

Sweden's Arcam AB has signed an agreement to acquire the AP&C division from Raymor Industries for a total of $35 million Canadian dollars. The move will see Arcam secure its supply of titanium powder used in the production of components via the company's Additive Manufacturing process.

AP&C is a global manufacturer of high quality metal powders and has been a supplier of titanium powders to Arcam since 2006. Titanium powder is an important part of Arcam's offering to its customers.

"With this acquisition Arcam secures access to the optimum production of high grade metal powders for our customers and we also add technology and expertise in powder metal production for 3D-printing in general and other advanced applications," stated Magnus René, President and CEO of Arcam.

AP&C uses proprietary plasma atomisation technology to produce metal powders, with titanium alloy powder being the largest product. A significant part of AP&C sales is to the 3D-Printing industry with other markets including Metal Injection Moulding (MIM), powders for spray coatings as well as powders for HIPed components. Arcam and the team at AP&C intend to continue expand the powder business and to advance the plasma atomisation technology.

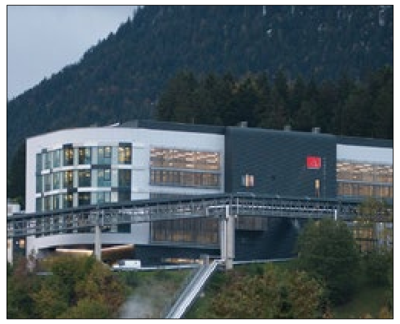
The AP&C division is expected to generate CAD$6.5 million of revenue during 2013 with an EBITDA result of around CAD$1.5 M. The acquired business, which currently employees 29, will become a subsidiary of Arcam and continue operating with the existing management team.

"With this deal we will be a part of the leading company in 3D-printing in metals. Because of our long term close cooperation with Arcam we know that this deal will give us a very good platform for continued growth in the 3D-printing industry. Being part of a larger group will also help in accelerating growth to better service the overall metal powder market", stated Jacques Mallette, President of Raymor Industries and future President of Arcam's powder business.

www.arcam.com

Ceratizit embarks on global growth strategy

Ceratizit, headquartered in Mamer, Luxembourg, is putting into place what it calls its sustainable growth strategy in order to increase the company's global presence. The cutting tool and wear part producer, a member of the Plansee Group, maintains an active presence in over 50 countries. The company supplies customers in the automotive industry, mechanical engineering, oil industry, medical systems, electronics and tools and mould construction.



The new Ceratizit hardmetal manufacturing plant in Reutte, Austria

Ceratizit reports that it will upgrade and expand production capacity at a number of sites including a new 7,800 m2 manufacturing plant in Reutte/Breitenwang, Austria. The new plant will allow the site to double its production of cemented carbide inserts and increase solid carbide rod production by up to 50%.

In the USA and India, Ceratizit has already expanded its regional manufacturing plants, and upgrading work is due to commence on the production facilities at the group's headquarters in Mamer, Luxembourg. The company is also expanding production capacity for tungsten carbide powder at its plant in Empfingen, Germany.

Thierry Wolter, Ceratizit board member in charge of cutting tools

"We have a clear understanding of the technical, logistical and other types of requirements Ceratizit needs to fulfil, both now and in the future, to satisfy our end customers, tool manufacturers and the technical tools trade," stated Thierry Wolter, Ceratizit board member in charge of cutting tools.

www.ceratizit.com

GKN Sinter Metals rewarded by Chinese automotive customers

GKN Sinter Metals has won awards from three leading automotive customers in China. Volkswagen, GETRAG and Tanhas all recognised GKN's operation in Danyang for the first time with their prestigious awards for consistent supplier quality.

Richard Lee, Sales Manager China, stated, "Receiving these awards is a great honour for GKN Sinter Metals Danyang. The key elements that enabled this milestone achievement are not only the long and close relationships to our customers, but also our fantastic team and the strong global network. We will continue to build strong relationships with our customers to achieve our strategic growth objectives."

GETRAG (Jiangxi) Transmission Co., Ltd., is a market leader for transmission products in China and GKN has worked with the business since 2008. Thanks to its outstanding product quality, the Danyang facility was honoured with GETRAG's CEO Special Award & Zero PPM 2013.

Volkswagen Automatic Transmission (Dalian) Co., Ltd., awarded GKN Danyang the Excellent Supplier of Quality Award in recognition of the plant's excellent quality performance in 2013 and the dedicated support over recent years. VWATD has been a GKN customer since 2010 and is the first wholly owned subsidiary outside of Germany to produce advanced dual-clutch automatic transmissions.

GETRAG's CEO Special Award was presented to GKN Sinter Metals

Tianjin Tanhas Technology Co., Ltd., also a customer of GKN since 2008, is the largest supplier of synchroniser systems in China with an annual production of more than 15 million pieces. Tanhas acknowledged the high quality and on-time delivery of GKN Danyang with its Excellent Quality Supplier Award 2013.

The Danyang facility was established in 2006, and supplies VW, GETRAG and Tanhas with 2.5 million synchroniser hubs annually, among other sintered transmission parts. Thanks to long-term partnerships and a focus on quality and communication with customers, GKN Sinter Metals China has managed to gain market share on a year-over-year basis and is now among the top five suppliers of the Chinese automotive Powder Metallurgy market.

www.gknsintermetals.com

China's Wuhan Iron and Steel Corp (WISCO) successfully delivers first exports of reduced iron powder

The Wuhan Iron and Steel Corporation (WISCO), China's first giant state owned iron and steel company and now the fourth largest steel maker in the world, has begun exports of reduced iron powder.

The company stated that earlier this month a shipment of reduced iron powder was delivered to a customer in Korea, marking the first international export of WISCO's Powder Metallurgy products and laying a solid foundation for further exports of the company's reduced iron powder.

Since the crisis in the steel industry in recent years, domestic consumption demand for its iron powder in China has declined, stated WISCO, "Atomised iron powder with higher purity at a lower price has squeezed the market share of reduced iron powder. The sales of reduced iron powder have been confronted with enormous setbacks."

"The quality and sales volumes of WISCO Powder Metallurgy products has been at the top in China for a long time. However, we failed to export the products. In the middle of 2013 the Powder Metallurgy Branch received a price inquiry and order from overseas," the company stated.

www.wisco.com.cn

EOS and 3D-Micromac form new company for Micro Laser Sintering technology

Germany's 3D-Micromac AG and EOS GmbH have announced the formation of a new company, 3D MicroPrint, with the aim of advancing the development and commercialisation of new Micro Laser Sintering (MLS) technology. 3D MicroPrint recently moved into new premises on the Chemnitz Smart Systems Campus in Germany.

Both 3D-Micromac and EOS have been developing MLS technology together since 2006 and the first system successfully began operation at a German research institute earlier in 2013. Joachim Göbner, formerly project head MLS at EOS and head of the technical centre Chemnitz, and Tino Petsch, CEO of 3D-Micromac, were appointed as business managers of the new company.

"Demand for very small parts which are difficult to manufacture using conventional processes is rising tremendously. Micro Laser Sintering provides solutions for three major trends: individualisation, functional integration, and miniaturisation," stated Dr Hans J Langer, founder and CEO of EOS GmbH.

"Working with layer thicknesses of ≤ 5 µm, focus diameters of ≤ 30 µm and powder particle size of ≤ 5 µm, the MLS technology opens up new dimensions. With MLS it is even possible to produce moveable component assemblies," stated Joachim Göbner, Business Manager at 3D MicroPrint.

Micro Laser Sintering is an Additive Manufacturing technology with parts built from metal powders, layer by layer, using a laser beam. MLS enables the production of parts with complex 3D structures offering a high

Micro laser sintering technology can be used to produce components that are impossible via other manufacturing routes

degree of freedom of design and the capacity to integrate and optimise functionality. Target applications include nozzles for the automotive industry, components for medical devices or the individualisation of jewellery. Growing demand for microparts can be observed in the areas of mould-making and aerospace technology.

http://3dmicroprint.de

Speciality Sintered Products receives Best Powder Metallurgy Product Award

Speciality Sintered Products PVT Ltd (SSPL), Pune, India, has received the Best PM Product Award (Ferrous Components) 2014 from the Powder Metallurgy Association of India (PMAI), for its integrated sensor wheel. The winning component integrates a sensing application and belt drive in one part and offers a cost saving of 30% over the traditional manufacturing process.

SSPL began operations in 2000 and claims to have the largest compaction press in India, an 800 ton Dorst press. The company has also installed a sophisticated Fluidtherm sinter hardening furnace at its facility.

A new plant at Shirwal, located 60 km from Pune, was recently commissioned by SSPL with an annual capacity of some 4000 MT of PM parts, including engine and

The award winning integrated sensor wheel from SSPL

transmission components.

"When our high temperature sintering facility is installed shortly we will offer the widest range of PM products in India," stated Mahesh Kamble, Manager Metallurgy, Speciality Sintered Products Pvt Ltd. "Our greatest strength, however, lies in our energetic and young, yet capable, team who see an opportunity in every challenge."

www.ssplpune.com

EPMA launches 2014 PM Thesis Competition

The European Powder Metallurgy Association (EPMA) has announced the launch of its 2014 PM Thesis Competition at both Diploma (Masters) and Doctorate (PhD) levels.

"The aim of the competition is to develop an interest in and to promote powder metallurgy among young scientists at European academic establishments and to encourage research at under-graduate and post-graduate levels," stated Joan Hallward, Thesis Competition Coordinator.

The competition is open to all applicants who have graduated from a European university and who have had their theses approved during the 2011-2014 academic years. The subject must be classified under the topic Powder Metallurgy. The thesis submission deadline is 2nd May 2014

www.epma.com

Arcam offers large EBM system for Additve Manufacturing in the aerospace industry

Sweden's Arcam AB has recently launched the Arcam Q20, a new Electron Beam Melting (EBM) system designed specifically for manufacturing in the aerospace industry. The new EBM system was developed with support from leading aerospace manufacturers and is based on Arcam's Q10 technology platform but with a larger build envelope (Ø350×H380 mm).

Arcam is primarily active in two market segments, the aerospace and the orthopaedic implant industries. The orthopaedic industry started using EBM systems in 2007, and today the process is well established with more than 30,000 EBM-manufactured orthopaedic devices implanted worldwide.

The Arcam Q20 EBM system

The aerospace industry is about to move into series production for several product applications, states Arcam, and the new Arcam Q20 provides several new features for industrial volume production, including increased productivity, higher resolution, and a camera-based monitoring system for part quality verification.

"With Arcam Q20 we sharpen our offering to one of our main markets, the aerospace industry. Arcam Q20 represents a new EBM generation, with a focus on continued industrialisation of the technology," stated Magnus René, CEO of Arcam. "Arcam Q20 strengthens our already strong product program for aerospace manufacturing, a market that puts high demands on both the technology and the application expertise. The first Arcam Q20 user will be Poly-Shape in France."

Arcam Q20 is designed for production of components for the aerospace industry, such as turbine blades and structural airframe components

www.arcam.se

2014 APMI Fellow Award recipients announced

John R Engquist, Consultant, JENS Solutions LLC., a recognised expert in the Powder Metallurgy industry, and Z Zak Fang, University of Utah Metallurgical Engineering Professor who is a world-renowned expert in the cemented carbides and titanium industries, have been selected to receive the 2014 Fellow Award from APMI International.

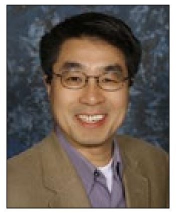
The fellowship is APMI's most prestigious award, recognising APMI members for their significant contributions to the goals, purpose and mission of the organisation as well as for a high level of expertise in the technology, practice or business of the industry. The two recipients will receive elevation to Fellow status at the PM2014 World Congress in Orlando during the Industry Luncheon on May 19, 2014.

John R Engquist

Over his 39 year career with Burgess-Norton Mfg. Co., Engquist has been intimately involved with every aspect of the PM part making process. A member of APMI for over 15 years, he has been a strong advocate of PM outreach through education and by proctoring several PMT Certification exams. He has been a well-regarded speaker at the annual Basic PM Short Course and PowderMet conferences.

A PM graduate of Hennepin Technical College, Engquist also has a BA in Business Management from North Central College. He is the sole or co-inventor on eight patents and received the MPIF Distinguished Service to PM award in 2007.

Z Zak Fang



With over 23 years of experience in the PM industry and APMI membership, Fang is known as a technology innovator and leader who has both rich industrial experience and academic rigour. Fang has been a mainstay at the MPIF PowderMet and Tungsten conferences, serving on the technical program committees, organising special interest programs, and acting as a speaker on numerous topics.

Fang received his BS in Powder Metallurgy and MS in Materials Science and Engineering at the University of Science & Technology, Beijing, China, and a PhD in Materials Science and Engineering from the University of Alabama at Birmingham, USA. He joined the University of Utah in 2002.

www.mpif.org

Project to look at Powder Metallurgy route for net shape nickel-base superalloys

The Advanced Materials and Processing Laboratory (AMPLab) based in the interdisciplinary research centre (IRC) within the School of Metallurgy and Materials, University of Birmingham, UK, along with MTC, Coventry, UK and CEIT, San Sebastian, Spain, are embarking on a two year research project with end-user partner Industria de Turbopropulsores (ITP), Spain, to develop a Powder Metallurgy route to manufacture static aero engine components such as an engine casing made from nickel-base superalloy Inconel 718.

Dr Raja Khan at AMPLab states that using the traditional casting/forging route results in a very poor material usage i.e. buy-to-fly ratios, which typically range from 3 up to 10. Current technology is thus inefficient and results in high costs together with a large environmental footprint.

The development and validation of a Powder Metallurgy based manufacturing route offers a clear potential in this, so the aim of this project is to develop and validate a cost-effective net shape hot isostatic pressing (NSHIP) manufacturing route for IN718 parts.

The project will establish the HIP processing window for IN718 powder and explore newly developed, low-cost canning manufacturing methods. Following the optimisation of HIP parameters components will be produced and assessed to see if they meet the end-user requirements in terms of accuracy, integrity and mechanical properties.

The research team working on this project at AMPLab includes Dr Raja Khan, Dr Khamis Essa, Professor Mike Loretto, and Dr Moataz Attallah.

www.birmingham.ac.uk

Two new Club Projects from EPMA

The European Powder Metallurgy Association (EPMA) has announced plans to launch two more Club Projects.

The first, 'Ultrasonic fatigue testing of hardmetals in the gigacycle regime - UFTH: Stage 2a' will run in partnership with TU Vienna, University of Vienna, CEIT San Sebastian, UPC Barcelona and NPL London. After the success of the UFTH 1 and UFTH 2 projects, a new testing strategy will be evaluated in order to decrease the duration and cost of the testing and, at the same time, increase the range of tested grades and properties.

The second, 'Toughness of PM HIP Steels Phase 2', is coordinated by RWTH Aachen and will be expanding work undertaken in the first phase using laboratory testing of selected materials.

www.epma.com

Global car sales growth to benefit Powder Metallurgy industry

The global auto industry is expected to generate 85 million unit sales in 2014, representing an increase of 4% on 2013, a year which also recorded growth of 3.5% to around 82 million units sold worldwide, according to research firm IHS Automotive.

By 2018 IHS forecasts sales to break the 100 million mark driven by rising wealth in emerging markets. "In every major economy in the world we are expecting economic growth," stated Charles Chesbrough, an economist with IHS. This is encouraging news for the global Powder Metallurgy industry which sells over 70% of all ferrous structural PM components to the automotive sector.

Europe

Following a year of a partial recovery in European vehicle sales in 2013, after six years of decline in new car sales, Europe should see growth of 3% in 2014 to around 14 million light vehicles according to a forecast issued by Deutsche Bank. From January to December 2013 the EU market recorded sales of 11.85 million new cars, a contraction of 1.7% over 2012, which had seen the new car sales market shrink by 8.2%.

The UK recorded a double-digit growth (+10.8%), while Spain posted a more moderate upturn (+3.3%). Germany (-4.2%), France (-5.7%) and Italy (-7.1%) all saw their demand for new cars decline. However, despite a decline in car sales to 2.95 million units in 2013, Germany saw domestic car production increase by 1% over the entire year to 5.45 million cars.

Russian car and light vehicle sales fell by 5.5% in 2013 to 2.78 million units following 3 years of strong growth. This leaves Russia in second place as the largest automobile market in Europe behind Germany. The Association of European Business (AEB) in Russia stated that it was expecting car sales to further decline by 1.6% in 2014 due to the 'muted' economic picture in the country.

Total vehicle sales in Turkey rose 10% year-on-year in 2013 to 853,378 units with car sales soaring ahead by 20% to 664,655 units, stated the Turkey Automotive Distribution Association.

America

The US market recorded a 7.5% increase in light vehicle sales to 15.651 million units in 2013. Deutsche Bank is forecasting US sales to increase by a further 3% to 16.03 million in 2014 and to peak at around 17 million light vehicle sales in 2017. Production in North America is also forecast to rise by 2.1 million vehicles between now and 2020 driven by new plants in the USA and Mexico. Asian car producers are expected to add more than 1 million units of that capacity.

Canadian light-vehicle sales reached a record 1,739,480 units in 2013, an increase of 4% on 2012, and topping the country's 11-year-old benchmark of 1,699,884 delivered in 2002 by 40,000 vehicles, or 2.3%.

In Brazil, the world's fourth-largest auto market, sales declined 0.91% in 2013 from a year earlier to about 3.767 million vehicles, according to Fenabrave.

Asia

Asia continues to be main engine for growth in automobile production and China has overtaken the USA as the single largest market for all vehicle types. In 2013 China became the first country in which more than 20 million vehicles were sold in any given year. The China Association of Automobile Manufacturers (CAAM) reported that in 2013, the production and sales of passenger cars were 18,085,200 and 17,928,900 units respectively, up 16.5% and 15.7% year on year. Both sales and production hit new records. Auto sales in China are expected to increase by 9 to 11% in 2014.

South Korean automakers sold a record 8.602 million vehicles last year, a 5% increase on 2012. Sales were fuelled by steady overseas demand for vehicles which largely offset weak domestic sales.

Automobile sales in Japan, the world's third biggest auto market, rose by just 0.1% in 2013 to 5.38 million vehicles, according to industry data. Sales are likely to continue growing year-on-year in the first three months of 2014 but the outlook thereafter is unclear after April when the sales tax will be raised.

India reported a 10% drop in car sales to 1.8 million units in 2013, the first fall in sales in 11 years.

EFFIPRO project looks at developing shorter Powder Metallurgy processes

The Energy Efficient Process of Engineering Materials (EFFIPRO) Project, part funded by the EU (FP7) and industry partners, was launched in September 2013. The objectives of this three year project are to develop a significantly shorter PM process using a new concept of hybrid electrical current assisted sintering, and hard materials with improved properties, thus resulting in a more energy efficient and cost effective process.

The project will focus on two different technologies, Electrical Discharge Compaction (EDC) and Electrical Resistance Sintering (ERS). The technology will be studied at fundamental level and pilot plant scale equipment will be designed and built.

High performance metallic composites (based on hardmetals, WC-Co) and engineering metallic materials are to be processed using this technology. It is stated that the use of this new technology will shorten the processing time and will produce materials with enhanced properties (hardness, toughness and lifetime), mainly due to the novel microstructures that will be obtained. In addition it is predicted that the use of this process will bring significant energy consumption reduction in the sintering process.

EFFIPRO states that tools for machining operations will be produced using this new technology. Two types of parts will be machined, one for the aerospace sector (made of Ti based materials or/and Carbon fibre composite) and the other for the automotive sector (made of Fe based materials). Objectives of the project are to:

- Implement a new PM process
- Introduce new materials to the market and help industry overcome the technical difficulties in their manufacturing processes
- Reduce manufacturing costs
- Substitute the use of critical elements and hazardous materials for more safe and environmentally friendly ones
- Reduce energy consumption by 20% during the process
- Increase the competitiveness of the European hard metals industry
- Complete a life-cycle analysis (LCA)
- Reduce by 25% the number of rejected parts
- Reduce emissions of greenhouse gases by 40%
- Reduce waste materials and increase the use of recycled materials by 10%.

The implementation cost of this new technology is expected to be in the same range or even at lower level than the current industrial processes.

www.effipro.org

Hoeganaes to discuss effectiveness of silicon in PM alloys at World Congress

At last year's PowderMet2013, held in Chicago, USA, Hoeganaes Corporation was presented with the Howard I Sanderow Outstanding Technical Paper award for its paper "The Influence of Silicon on the Mechanical Properties and Hardenability of PM Steels." During this year's PM2014 World Congress in Orlando, Florida, Hoeganaes will explore the topic further with a presentation entitled "Diffusion Behavior and Microstructural Transformations of PM Steels Containing Silicon."

In the award winning presentation, the Hoeganaes team studied the effects of silicon additions to PM alloy systems. Silicon is an abundant alloying element, being the second most available element in the earth's crust and therefore a very cost effective element for use in steel.

The microstructures, mechanical properties and hardenability of Powder Metallurgy alloy systems were investigated and it was demonstrated that the addition of silicon can increase strength in both the sintered and heat treated conditions. In the sintered condition silicon strengthens the ferrite of the pearlitic microstructure by solid solution hardening. In the heat treated condition silicon was found to increase the hardenability of low alloy steels and when used in combination with chromium, manganese or molybdenum was seen to increase hardenability over that if these elements were used alone. The increase in hardenability was such that alloys containing silicon were able to be sinter-hardened using accelerated cooling.

During this year's presentation, Hoeganaes will explore this topic more fully. The effectiveness of the silicon is dependent on the distribution of the element throughout the material volume, which is determined by the diffusion during sintering. The distribution of silicon and interaction with other elements are quantified using energy dispersive spectroscopy on multiple compositions prepared using different alloying methods.

In addition, the effects of the diffusion on hardenability are being addressed by estimating the volume percent of the various transformation products in cross-sections of hardenability samples. This increased knowledge of the diffusion of silicon in PM alloys, and its interaction with other alloying elements, will lead to a better understanding of the sintering requirements for the end user, states Hoeganaes.

www.gkn.com/hoeganaes

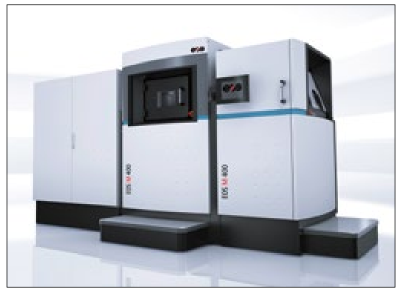
EOS introduces M 400 Additive Manufacturing machine for metal sector

EOS GmbH has announced a new machine for production of metal parts made by the Additive Manufacturing (AM) processes. The company's new EOS M 400 will enable the manufacture of larger components and increases the level of automation still further.

The EOS M 400 is based on a modular concept and is initially available with both set-up, and process stations. A further development of the EOS M 400 is the size of the building chamber, which measures 400 x 400 x 400 mm so that larger components can now be produced. The first systems will initially be offered with the EOS Aluminum AlSi10Mg and EOS NickelAlloy IN718 materials and will be particularly suited for use in the automobile and aerospace sectors. Processes for further materials are still in the development phase, including both tool steel and titanium.

The EOS M 400 laser has a performance of up to 1,000 watts, allowing the use of new materials that require more powerful lasers. From 2015, EOS is planning to also offer the EOS M 400-4 which will come with four lasers. While the single-laser version opens the way for the development of new applications, the focus of the multi-mode variant lies in achieving productivity increases.

"EOS is pursuing a platform-based strategy for the metal technology and is able to support its customers from the research and development phase, through to the series production. The EOS M 400 represents the key to the industrial series utilisation of Additive Manufacturing. If the EOSINT M 270 and EOSINT M 280 models have set the technical benchmarks, then the EOS M 400 takes these a step further. The new system supports users not only in the context of its qualification for production, but also in actual manufacturing applications. We won't be drawing the line at a single solution. We will be expanding the platform with successive performance modules," stated Adrian Keppler, Managing Director at EOS.



The EOS M 400

An oil separator for a racing car built in an EOS M 400 from EOS Aluminium AlSi10Mg powder

www.eos.info

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€18.8 million AMAZE project to focus on development of large defect free Additively Manufactured metallic components

A Concept M2 Cussing System in use at the AMPLab

The Advanced Materials and Processing Laboratory (AMPLab) based in the interdisciplinary research centre (IRC) within the School of Metallurgy and Materials, University of Birmingham, UK, is embarking on a new project in January funded by the European Union's FP7 Programme called AMAZE – Additive Manufacturing Aiming Towards Zero Waste and Efficient Production of High-Tech Metal Powders.

Nick Adkins at AMPLab states that the over-arching goal of AMAZE is to rapidly produce large defect-free Additively Manufactured (AM) metallic components up to two metres in size, ideally with close to zero waste, for use in aeronautics, space, automotive, nuclear fusion, and tooling.

Four pilot-scale industrial AM factories will be established and enhanced by 2016 with the objective of giving EU manufacturers and end users a world-dominant position with respect to AM production of high-value metallic parts. A further aim is to achieve 50% cost reduction for finished parts, compared to traditional processing.

During the 4 ½ year programme AMAZE will also aim to dramatically increase the commercial use of adaptronics, in-situ sensing, process feedback, novel post-processing and clean-rooms in AM, so that overall quality levels are improved, dimensional accuracy is increased by 25%, build rates are increased by a factor of 10, and industrial scrap rates are slashed to <5%.

Scientifically, the critical links between alloy composition, powder/wire production, additive processing, microstructural evolution, defect formation and the final properties of metallic AM parts will be examined and understood. This knowledge will be used to validate multi-level process models that can predict AM processes, part quality and performance.

The €18.8 million research project embraces 31 partners, 21 from industry, eight from academia including AMPLab and the Mathematics Dept at Birmingham, and two from intergovernmental agencies. This is said to represent the largest and most ambitious team ever assembled on AM.

www.birmingham.ac.uk

Fachmetall Awards given to USD Formteiltechnik and Zeitlauf antriebstechnik

Fachmetall GmbH, a metallurgical laboratory specialising in investigations of Powder Metallurgy materials, based in Radevormwald, Germany, presents its annual PM Qualification Award and QM Context Award to organisations with a focus on PM technology and a dedication to excellent product quality. USD Formteiltechnik GmbH and Zeitlauf GmbH antriebstechnik & Co KG have recently been announced as this year's recipients.

USD Formteiltechnik GmbH, Meinerzhagen, Germany won the PM Qualification Award. USD is a supplier of structural steel parts made by various manufacturing technologies such as investment casting, die forging, stamping, press-and-sinter as well as MIM. The high proportion of Powder Metallurgy products in USD's portfolio reflects the awareness and appreciation of this technology in the activities of USD.

Zeitlauf GmbH antriebstechnik & Co KG in Lauf an der Pegnitz, Germany, is a manufacturer of precision gearboxes mainly for electric motors. Zeitlauf's planetary, spur gear and angular gearboxes consume large

Presenting the Fachmetall PM Qualification Award to USD Formteiltechnik GmbH (left to right): Thorsten Klein (USD), Holger Davin (Fachmetall), Joachim Steiner (Award Jury), Christian Kosak (USD)

quantities of PM parts. Regular quality control procedures include not only dimensional testing, but also measurement of the hardness and density and inspection of the microstructure. Zeitlauf was awarded the prize in recognition of its dedication to excellent product quality and its long-lasting cooperation with the PM industry.

www.fachmetall.de

PM2014 World Congress Technical Programme published

The Technical Programme has now been published by organisers of the 2014 World Congress on Powder Metallurgy & Particulate Materials, Orlando, USA, May 18 – 22, 2014.

The 2014 World Congress on Powder Metallurgy & Particulate Materials is organised by the Metal Powder Industries Federation (MPIF) and APMI International. The conference includes oral and poster presentations along with a series of Special Interest Seminars.

The conference will open with a Keynote Presentation by Bob Lutz, Former Vice Chairman, General Motors Corporation, and author of "Car Guys vs. Bean Counters" and "Icons and Idiots". Bob Lutz is one of the most experienced and high- profile auto executives in the world. Having been in the business for almost 50 years, he has left an indelible mark on all three of the big US automakers, most recently GM, where he reinvigorated its previously undistinguished vehicle lineup.

Lutz is the highest-profile guest speaker to speak at an MPIF conference, and his presentation and message should resonate with all in the PM industry.

There will also be a major exhibition at PM2014, with some 175 booths showcasing leading suppliers of PM and particulate materials processing equipment, powders, products and additive manufacturing.

www.mpif.org

Höganäs introduces new flow rate analysis method for customer mixes

As a response to the new standard for flow analysis of metal powder mixes, published by the ISO Committee on the 1st of May 2013, Höganäs has decided to change its method of analysing the flow rate on customer mixes.

The new method, Flow Gustavsson (ISO 13517:2013), was implemented on the 1st of September and has since, after customer approval, been used to analyse the flow rate on all new customer mixes.

The main technical difference between the two methods is that the cone angle for Flow Gustavsson is 30° which is half the angle of Flow Hall, stated Product Manager Mixes Georgia Gahnsby, Höganäs Global Development.

The change from the Flow Hall (ISO 4490) method to Flow Gustavsson only concerns the method of analysis, thus not affecting the quality of the mixes in any way. The main benefit with the new method is that the produced mass flow provides continuous flow and eliminates the formation of rat holes observed in the Hall funnel flow.

Since the inclination for flow stop is much smaller with Flow Gustavsson, the method can be used to measure a wider range of powder mixes and it is better suited for characterisation of press-ready mixes. Flow Hall will continue to be used for powders not containing any additives.

www.hoganas.com

The new Flow Gustavsson adopted by Höganäs

HIP '14 Conference Programme published

The conference programme has been published for HIP '14, the 11th International Conference of Hot Isostatic Pressing (HIP), Stockholm, Sweden, June 9–13 2014.

This triennial conference will focus on trends, developments and innovations in three key areas; oil and gas, power generation and aerospace. Speakers from Total, GE Oil & Gas, Areva, Rolls Royce, SNECMA, Aerojet Rocketdyne, Aker Solutions and IHI Corp are amongst those featured in the conference programme.

The conference will cover topics such as material development, production of Near Net Shape (NNS) components, part design and process modelling. Aspects related to Powder Metallurgy processing, diffusion bonding and part densification will also be included.

www.hip14.se

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Increasing density and reducing lubricant content with AncorMax 225 from Hoeganaes

As the applications for Powder Metallurgy (PM) structural parts become increasingly more demanding there is a need for parts with higher strength, hardness, and ductility. The most effective way to satisfy customer needs and achieve improvements in all of these areas simultaneously is to raise the density of the compacted parts, claims Hoeganaes Corporation.

"Because of the desire for higher and higher densities, it is the responsibility of both the parts maker and powder producer to develop ways to improve density across the board for an array of material compositions," stated Tim Hale, Global Marketing Manager, Hoeganaes. "This has been achieved at Hoeganaes Corporation using an advanced lubricant and binder system called AncorMax 225."

"The AncorMax 225 system is becoming popular among customers who desire high density parts. The material is currently used at more than 20 of our customers for applications worldwide," added Hale.

In order to achieve high density parts, it is vital to reduce the total amount of lubricant in the powder premix, as lubricants have a significantly detrimental effect on the maximum green density that can be attained during compaction. The value of the maximum green density achieved if all porosity was removed is known as the pore free density (PFD). While lubricants are necessary for protecting parts and tooling during forming and ejection, for each 0.1% lubricant added to a premix, there is a 0.05 g/cm^3 loss in PFD.

Fig. 1 shows the effect of both graphite and lubricant content in a premix on achieving 98% of the PFD, which is generally the highest that can be attained during compaction. Thus, to achieve higher green and sintered densities via single press single sinter processing, lower lubricant levels are necessary. The AncorMax 225 system utilises warm die compaction technology and allows for lubricant levels as low as 0.25%, which enables for green densities in compacted parts up to approximately 7.5 g/cm^3.

By raising green and sintered densities, overall strength, hardness and ductility in PM parts can be improved dramatically. Physical properties such as transverse rupture strength, apparent hardness, ultimate tensile strength, and Charpy impact toughness are directly related to part density. Fig. 2 shows the elevated green density values that can be achieved in an FLN2-4405 mix with the AncorMax 225 system compared to another high density system, AncorMax 200, and a standard premix with 0.75% Acrawax.

In addition to increasing part density and strength, the AncorMax 225 system gives several other advantages including better material flow, improved part-to-part consistency, higher green strength, reduced part ejection forces, and lower burn-off emissions during sintering. By nearly doubling the green strength of a compacted part, this advanced lubricant system allows for easier part handling with less cracking and chipping in the green condition. Meanwhile, the reduction in the ejection forces is extremely beneficial for reducing scoring on the part, die, and punches, while increasing overall tool life. As an added benefit, the lower burn-off emissions can lead to lower maintenance costs.

www.gkn.com/hoeganaes

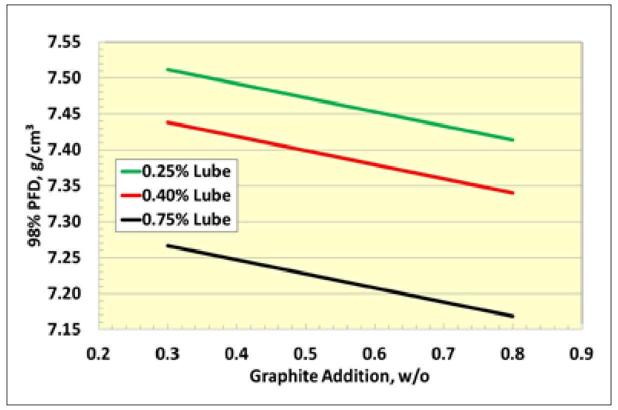


Fig. 1 98% PFD vs. graphite addition for three lubricant levels

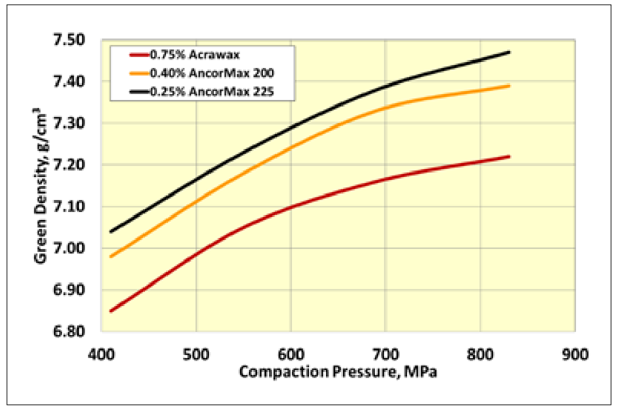


Fig. 2 Green density vs. compaction pressure for three lubricant systems

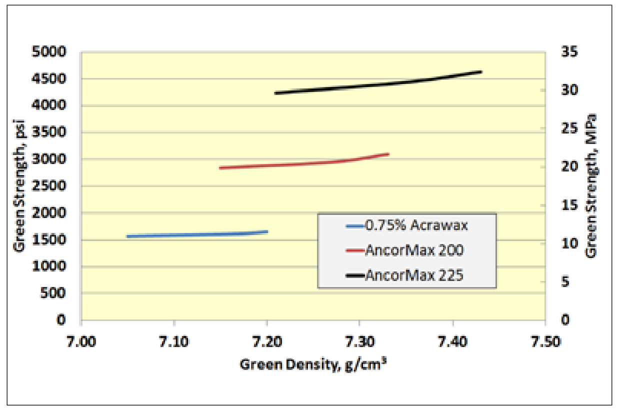


Fig. 3 Green strength vs. green density for three lubricant systems

Large titanium wing spar made by Additive Manufacturing

The Northwestern Polytechnic University (NPU) in Xi'an, Shaanxi province, is one of China's leading research oriented universities. The Solidification Processing Laboratory at NPU has been focusing on aeronautics, astronautics and marine technology and has been involved in laser additive manufacturing (LAM) since 1995.

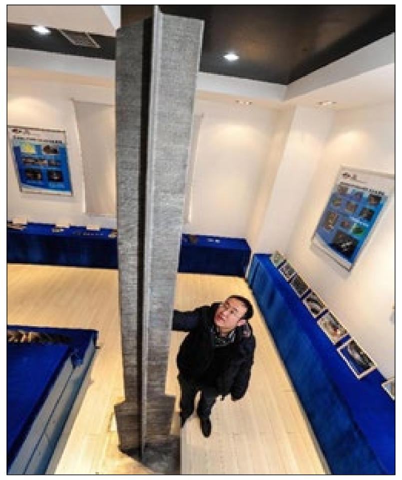
The laboratory has built two LAM machines using CO2 and YAG lasers of several kilowatt beam power to process advanced materials such as superalloys, stainless steels and titanium alloys. The oxygen content of the argon filled in the LAM chamber can be measured and strictly controlled.

The LAM technology developed at NPU has found its way into the Comac C-919, China's first domestically-designed commercial aircraft which is going into series production in 2014 and into commercial service in 2016. The LAM part is a central wing spar made from titanium alloy and is reported to be three metres long. Its mechanical properties meet the standards for forged parts.

The laser additive manufacturing technology is said to provide significant advantages over traditional manufacturing methods. "The modern aerospace industry has stringent requirements, so complex additive manufacturing processes must be developed to ensure that products can achieve the robust performance levels previously established by traditional manufacturing methods," stated Huang Weidong, director of the Solidification Processing Lab at NPU.

LAM technology is also reported to have found applications in China's fighter aircraft J-15 and J-16 jets, the J-20 stealth fighter and the next-generation J-31 fighter. Earlier this year at the 16th China Beijing International High-Tech Expo, China's AVIC Heavy Machinery Co received the state technological invention award for the world's largest LAM titanium part for military aircraft.

web.nwpu.edu.cn



Wing spar produced at NPU for China's Comac C-919 aircraft

APMA 2013, 2nd International Conference on Powder Metallurgy in Asia, held in Xiamen, China

Yulin Xiao and Prof Randall German meet at the Powder Metallurgy Review exhibition booth

APMA 2013, 2nd International Conference on Powder Metallurgy in Asia, was successfully held in Xiamen, China from November 3rd to 6th, 2013. Organised by Chinese Strategic Alliance for Technological Innovation in Powder Metallurgy Industry (SATI-PM) in conjunction with Taiwan Powder Metallurgy Association (TPMA), the event attracted over 500 participants from international business and research institutes.

The theme of the conference was "Powder Metallurgy- Challenge and Development in Asia" and included extensive coverage and discussion on the challenges and opportunities for Powder Metallurgy, the status quo and prospective application of new theories, materials, technology and PM products.

Leading experts from both Asia and the international PM community presented over 100 oral papers at the conference. There were over 100 poster presentations along with an award ceremony recognising the best papers.

Technical reports and papers were focused on iron and copper base parts, refractory materials and Hardmetals, PM functional materials, powder forming, post-processing and non-ferrous materials. An in-depth discussion was launched on PM technology, its development status and trends in various countries, bringing up the strategic direction and technology roadmap of the PM industry.

Running alongside APMA 2013 was the 2013 China Powder Metallurgy Conference and Cross-Strait Powder Metallurgy Technology Seminar, the Third Session of the First SATI-PM Committee Conference and an APMA Committee Conference.

The event included a large exhibition attracting both local and international companies along with a good number of visitors. *Powder Metallurgy Review* and our sister publication, PIM International, were represented in the exhibition and distribution of both magazines took place from our exhibition booth.

www.apma2013.org

APMA 2013 conference gallery

Powder Metallurgy products in fuel efficient and environmentally friendly vehicles

Kei Ishii of the Powder Metallurgy Development Department at Hitachi Chemical, Japan, recently reported on efforts his company has been making to develop new Powder Metallurgy (PM) products to improve the efficiency of both conventional IC engine cars and hybrid and electric vehicles [1].

The continuing increase in global demand for automobiles will not only put huge pressure on future reserves of fossil fuel to power these vehicles, it will also have a detrimental impact on the global environment through increased air pollution and the build up of greenhouse gases from CO_2 emissions. There are estimates that global primary energy demand for automobiles alone will increase by 40% by 2030, mainly propelled by petrol/diesel consumption, if no appropriate energy saving measures are undertaken.

The automotive sector and its suppliers are accordingly accelerating efforts to develop new technology and materials which will improve the fuel efficiency of internal combustion (IC) engines and thereby reduce greenhouse gas emissions, and they are continuing to make improvements also to hybrid (HV), electric vehicles (EV), and fuel cell vehicles (FCV).

Turbochargers

One way of improving overall fuel efficiency is by downsizing engines yet maintaining the equivalent power output of the larger engines they have replaced. In the case of turbochargers, downsizing requires the PM parts used in them to have increased wear resistance at higher operating temperatures.

Hitachi Chemical met the challenge by developing a new steel-based sintered material with 20% Cr content designated 'EW-50'. The Cr content is finely and uniformly dispersed in the matrix as Cr carbide (30% ratio area) (Fig. 1), and the sintered material was found to have excellent wear and oxidation resistance even at temperatures of 700°C or higher.

Ishii stated that Hitachi Chemical has also developed Cr containing PM steels to replace former Ni-PM steels to produce lighter or thinner walled automotive PM parts in order to save weight but without sacrificing strength.

Idling stop systems

Idling stop systems are increasingly being used to shut down the engine when the driving speed decreases to a certain level, and then restart the engine when the accelerator pedal is pressed.

The starter motor used in an idling stop system must be more durable and less noisy than existing starter motors and Hitachi Chemical has developed a Cu-based sintered bearing material designated KCR-1 which contains a solid lubricant dispersed in the bearing. The solid lubricant reduces the friction coefficient of the sintered bearing and also reduces the squeals generated by the sliding surfaces.

Diesel engine fuel injector

Ishii reported that Hitachi Chemical has developed a stator core for a solenoid valve used in a common rail high speed, high precision fuel injector mechanism for diesel engines. The stator cores, made from soft magnetic composite iron powder, are used to open and close diesel fuel injection valves.

The fuel injector stator core (Fig. 2) is produced by compacting the electrically insulated SMC iron powder and the resulting compacts have reduced iron loss (thermal loss) in the AC magnetic field. The SMC iron powder magnets do not require sintering.

Valve train parts for flexible fuel vehicles

Flexible fuel vehicle engines use bio-ethanol as a replacement for petrol and natural gas and offer cleaner combustion and hence cleaner emissions. However, the valve seats have a tendency to adhere and wear due to the high frequency of metal contact

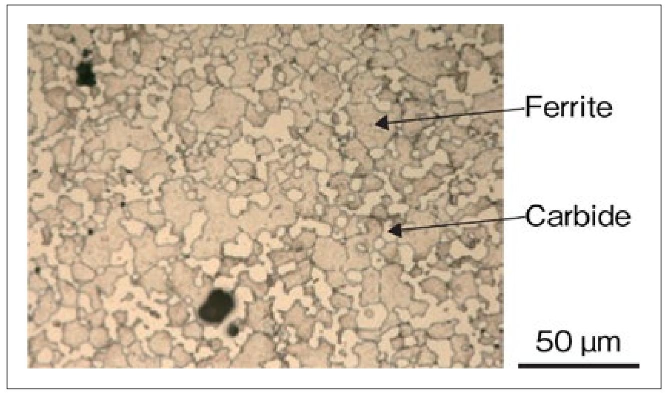


Fig. 1 Microstructure of high Cr content sintered 'EW-50' material having high heat and wear resistance. (Courtesy Hitachi Chemical, Japan)

Fig. 2 Fuel injector stator cores used in diesel engines (Courtesy Hitachi Chemical, Japan)

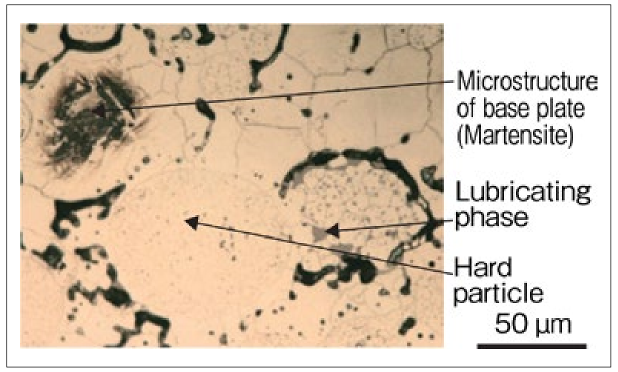


Fig. 3 Microstructure of sintered valve seat material EH-51H (Courtesy Hitachi Chemical, Japan)

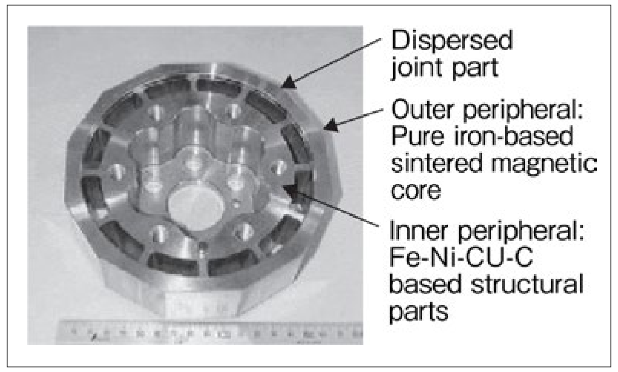


Fig. 4 SMC motor rotor core for hybrid vehicles (Courtesy Hitachi Chemical, Japan)

between the seat and the valve, and a suitably wear resistant valve seat material must be used.

Hitachi Chemical developed its EH-51H sintered valve seat material for Flexible fuel vehicles which showed improved anti-adhesion properties thanks to the combination of dispersed hard particles in the sintered matrix and the inclusion of a uniformly dispersed solid lubricant (Fig. 3)

Ultra-high porosity parts for engine heat insulation

A number of thermal management materials have been introduced in recent years to improve the fuel efficiency of vehicles. Ishii reported that Hitachi Chemical had developed a 316L stainless steel porous metal with maximum porosity up to 95% which he stated exceeds all previous porosity levels achieved by the powder metallurgy route.

The porous metal is said to be characterised by a fine porous binary structure, the open-pore type with continuous coarse-scale pores and the closed-pore type with independent closed pores. The closed type porous stainless steels can be used to retain heat inside a combustion engine leading to highly efficient combustion.

Reactor core for in-car inverters

In the HV and EV sector Hitachi Chemical has developed a soft magnetic composite (SMC) iron powder reactor core used to increase voltage through the inverters in electric vehicles (Fig. 4).

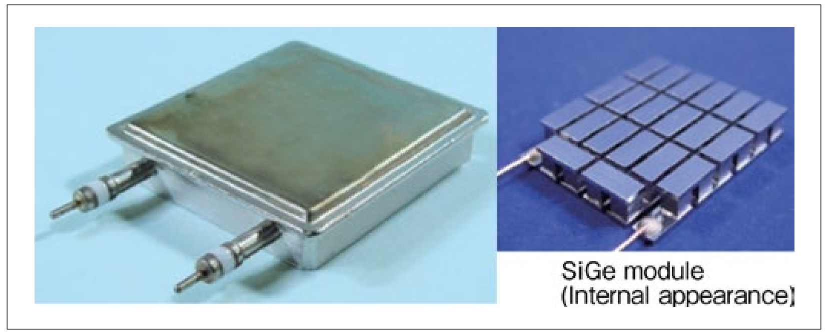


Fig. 5 SiGe thermoelectric and encapsulated models used for waste heat regeneration. (Courtesy Hitachi Chemicas, Japan)

The reactor core combines high magnetic flux density and low hysteresis loss, and its surface is coated to give the SMC material great stability at high temperatures. The cores can be mounted not only in the inverters of HVs and EVs but can also be used in solar panels, hot water supply systems using heat pumps, and in wind turbines.

Thermoelectric regeneration of waste heat

Ishii also reported that Hitachi Chemical has developed thermoelectric conversion technology directly capable of converting thermal energy to electricity which the company anticipates being used for waste heat regeneration from automobiles as well as from industrial furnaces.

Ishii states that a Powder Metallurgy method is used to produce the thermoelectric modules from environmentally friendly materials such as SiGe, Mg_2Si, and Mn1.8Si in which reduced thermal conductivity is achieved via micronization of crystals. By decompression-sealing the encapsulated modules, the thermal contact resistance between the module and contacting case can be reduced to an extent that underlines their potential use within high temperature and corrosive environments.

Reference

[1] Kei Ishii, Trends in environmental and energy saving technology for automobiles and corresponding developments in Powder Metallurgy, published in *Hitachi Chemicals Technical Report*, Vol.55, 2013, pp50-53.

www.hitachi-chem.co.jp

Optimising tooling for Powder Metallurgy: Design, materials and best practice

The optimisation of tooling is essential for ensuring improved efficiency in the manufacture of Powder Metallurgy components. Tooling represents a significant investment, so the correct design, choice of materials and tool maintenance is critical in minimising costs. Tool failure is expensive and no doubt will have been experienced by most companies at some time. In this article David Lemon, Consultant, Mechworx Ltd, discusses the various ways in which PM companies can avoid tool failures by focussing on tool design and optimisation.

It can be argued that many companies are far too process focussed, putting great efforts into making sure a tool will produce the Powder Metallurgy part, but far less effort into extending tool life. The main area of tool design input concerns the features that will produce the part, what can be referred to as the business end of the tool, whereas less input is given to the non-business end which comprises the clearance and supporting areas.

Tool optimisation is focussed on extending the life of a tool, resulting in less production downtime and more cost effective parts. To manufacture tooling economically one needs to understand design for manufacture. This means designing a tool so that it can be manufactured in the most efficient way using the available processes [Fig. 1].

It is important to understand the available machining processes, either in-house or at a supplier. To do this it is nesessary to visit the supplier and in-house toolroom, evaluate the available machines and discover what manufacturing processes are possible. This sounds quite basic but it is surprising how few PM companies fully understand their suppliers' capabilities.

The machining processes for tool production typically follow the order of turning, milling, grinding, spark-erosion, lapping and polishing. Heat treatment is excluded from the list because it is usually outsourced.

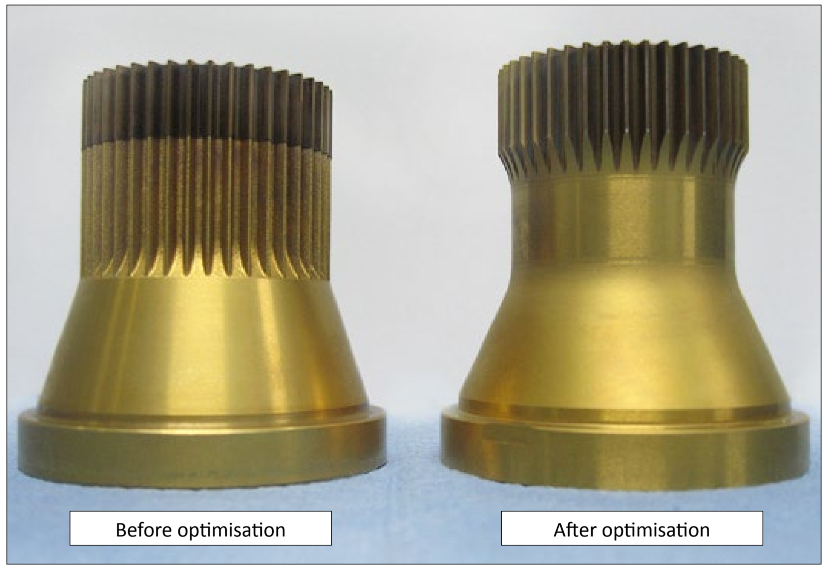


Fig. 1 The original design of the punch was optimised to remove the unnecessary and expensive spark eroded form (Courtesy Mechworx Ltd)

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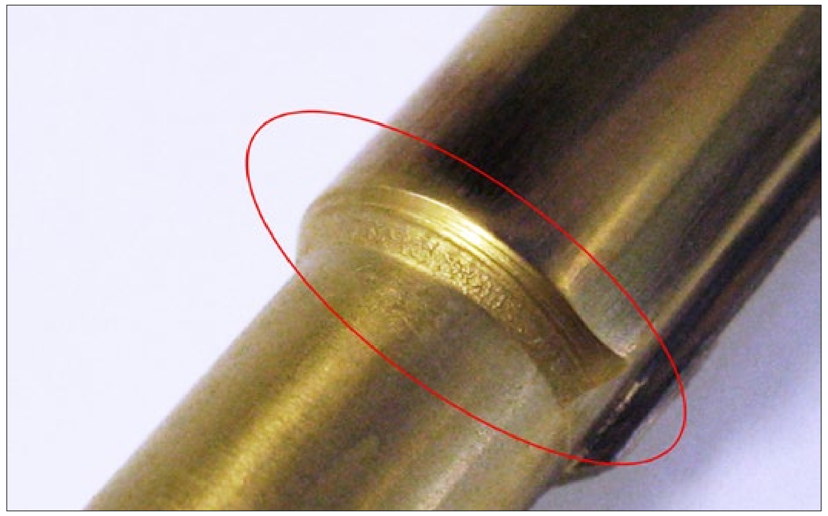

Fig. 2 When turning, try to avoid sharp corners by using a blend radius to make the geometry flow. The sharp corner and rough finish pictured can weaken the tool (Courtesy of Mechworx Ltd)

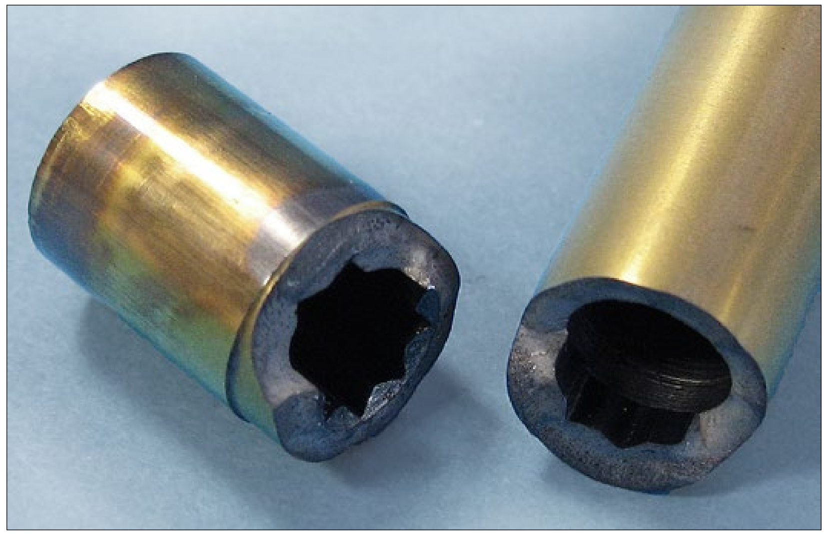

Fig. 3 Punch failure caused by a sharp corner at the internal intersection of drilled clearance hole and form (Courtesy of Mechworx Ltd)

Planning for production

PM toolmaking involves single unit production and, unlike mass production, the luxury of first-off inspection rarely exists. There is no batch of parts with a percentage scrap allowance, therefore it is necessary to take a "belt and braces" approach to manufacturing. Before discussing some of the various machining processes, the required approach to toolmaking should be identified.

It is essential to develop a precision mind-set and learn the discipline that near enough, is not good enough. Successful toolmaking is only achieved by "chasing the microns" and the old adage of, "the more you leave to chance, the less chance you have," is never more applicable than to precision toolmaking

Detailed production planning is required. Try to visualise the individual processes needed to make the tool. Having completed this task one can arrange them in order so that the variables of a given production process are controlled, thus ensuring the required precision is achieved. For example, it is easier to accurately position and grind the outside diameter of a punch than to accurately position and wire erode the inner form. Therefore the inner form is produced first, the outer diameter is then positioned relative to the inner form and then ground to size. The positioning variables of wire erosion are controlled during the grinding operation. Before citing the accuracy of the newly acquired wire erosion machine, one needs to appreciate the big difference between theory and practice. Operations are sometimes done in what seems like a non-logical order to ensure precision is achieved.

After heat treatment establish a datum and if necessary pre-grind diameters or faces to assist several operations, for example erosion and cylindrical grinding.

Optimisation of the production processes

Turning

Often considered a roughing operation, turning is the starting point of tool optimisation. Here one can prevent features that receive no further machining from becoming stress raisers. One only needs to consider punch form clearance, core rod adapters and internal bores to appreciate the opportunity to extend tool life and reduce crack propagation.

In addition to producing a good surface finish, where possible blend geometry changes with a defined radius rather than the standard cutting tool radius. This is particularly important when producing the clearance on punches. By making the geometry contour flow from feature to feature, rather than a series of straight lines, it is possible to prevent premature tool failure [Fig. 2]. Where a drilled finish cannot be avoided, produce a small radius on the outside edge of the drill to avoid sharp internal geometry [Fig. 3].

External threads on core rod adapters should have a radius undercut where the thread joins the adapter. Modern CNC machines produce a better finish than manual lathes, but manual lathes remain an important part of the modern machine shop. Often it is not just about speed and programming, manual machining can provide a more flexible approach to turning.

Milling

Traditionally, manual milling operations have provided a means of rapid stock removal and the ability to produce complicated geometry. However, when using form cutters for milling the clearance area of tooth forms, for example, the shape produced was always a compromise of best fit based on the available cutting tools. The surface finish sometimes needed to be hand finished to improve the tool's fracture resistance.

Modern CNC milling machines or machining centres, equipped with up to five axes, spindle speeds in excess of 40,000 rpm and coupled with the latest CAD/CAM software, can produce complex geometry on soft and hardened materials [Fig. 4]. CNC milling achieves a better surface finish and provides the opportunity for producing smooth blend radii between geometries. Once again, premature tool failure can be prevented by blending different geometries, this is particularly important in the clearance areas.

Electro Discharge Machining (EDM)

This process is also known as spark-erosion, ram-erosion or sparking, to name but a few. The EDM process works by immersing two artefacts (electrode and workpiece) in a tank containing oil based dielectric fluid. An electric current is then passed through the electrode while moving it towards the workpiece, in this case a PM tool, until the gap between the two artefacts is small enough for the current to jump or spark across the gap. As the spark jumps onto the tool it superheats the surface and creates a small molten pool of the tool material. The electrical controller then switches off the current and the spark stops. As the dielectric fluid replaces the spark it chills the molten pool, thus releasing a small globule of the tool material and flushing it away. The surface of the electrode is sparking onto the tool surface many thousands of times per second and the process continues until the tool surface is eroded away to replicate a negative image of the electrode geometry. The electrode is produced with an oversized or undersized geometry of the shape required on the tool, depending on whether an external or internal shape is required. The difference between the electrode and tool geometry is known as the 'spark gap'.

Traditionally, several electrodes were used to produce the required shape on the tool, each having a different spark gap to allow for roughing, semi-finishing and finishing of the tool geometry. Today, with modern spark erosion machines, it is possible to reface a worn punch with electrodes prepared with the same spark gap [Fig. 5]. The advantage of this method is that electrode manufacture is standardised and the number of electrodes needed to reface the punch is reduced.

One downside to the EDM process is that the eroded surface is comprised of thousands of highly stressed quenched pools from which the material was removed. This produces what is known as the recast or white layer. The removal of the recast layer is critical to the effective use of a tool and must be done by re-

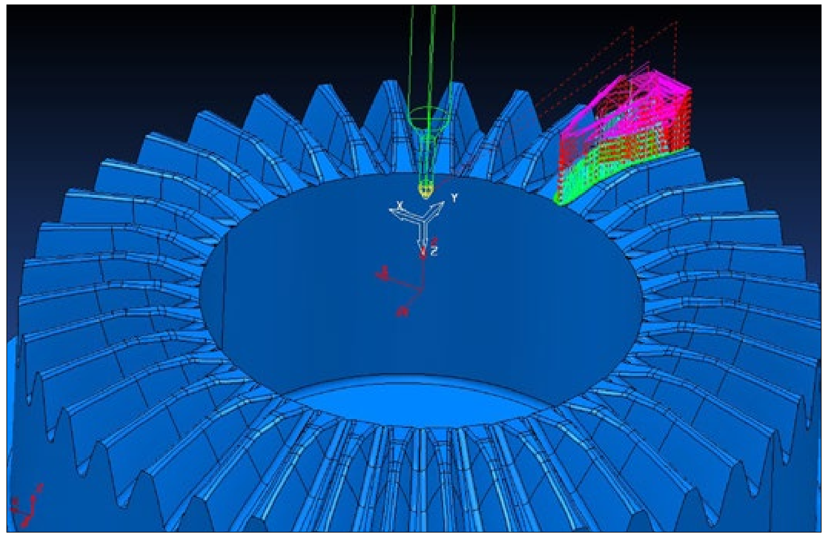

Fig. 4 Modern CNC milling machines coupled with the latest CAD/CAM software, can produce complex geometry (Courtesy Mechworx Ltd)

Fig. 5 With modern spark erosion machines it is possible to reface a worn punch with electrodes prepared with the same spark gap (Courtesy Hua Cheng Steel Mould Co. Ltd)

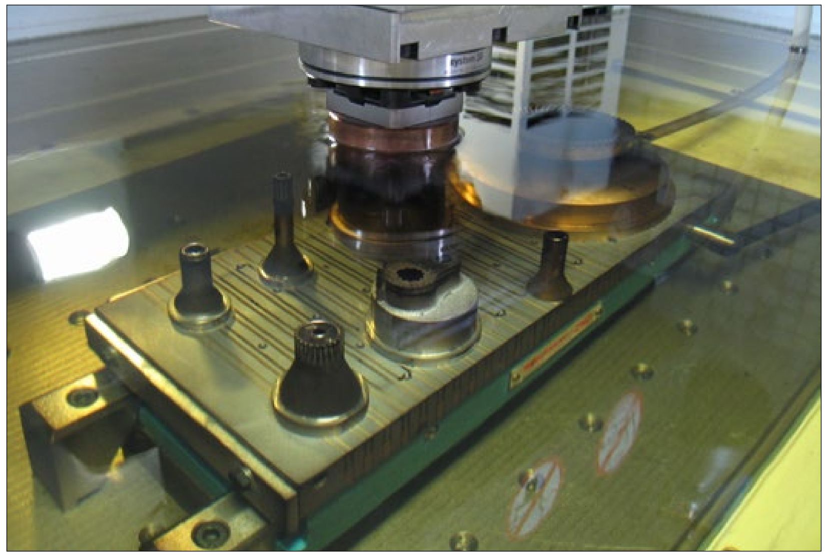

Fig. 6 Multi-part setting is necessary to justify the investment and to maximise efficiency of the EDM process (Courtesy Mechworx Ltd)

tempering the tool at approximately 45°C below the original tempering temperature. Failure to remove the recast layer will almost certainly result in premature tool breakage.

There are several ways to optimise the EDM process for toolmaking. The process can best be optimised by taking advantage of the modern CNC erosion machines, most of which have a storage carousel to enable the use of multiple electrodes. Careful preparation and the use of low-flux magnetic tables with integral flushing holes can allow the 'lights out' machining of multiple punches. Multi-part setting is necessary to justify the investment and to maximise efficiency [Fig. 6].

Electrode preparation is vital to producing accurate, precise geometry and the use of a standardised workholding system is strongly recommended. There are several systems available, namely from Erowa, Hirschmann and System 3R, with each system having its own design and unique aspects, but all providing an accurate reference system to ensure a precision location [Fig. 7].

<u>Advantages of EDM machining:</u>

- Machining of a complex geometry that is not possible with conventional machining
- Unlike conventional machining, there are no cutting pressures associated with EDM, thus it's possible to produce fine detail on delicate tools
- A smooth surface finish is achievable, thus reducing the amount of manual polishing required and maintaining highly accurate geometry
- High hardness materials can be machined to very close tolerances.

Wire Electrode Discharge Machining (WEDM)

Often referred to as wire-erosion or wire-cutting, WEDM works on a similar principle to EDM but it uses a small diameter wire instead of an electrode, typically measuring 0.25 mm diameter. The machining takes place in a tank containing deionised water as opposed to the oil based dielectric fluid used for EDM. The wire is positioned by diamond wire guides and its path is CNC controlled.

The introduction of the first WEDM machines revolutionised the manufacture of PM tools. It was now possible to produce a die form by simply programming a shape as opposed to the labour intensive manufacture of electrodes and time consuming EDM machining. Punches too are now being made from two-piece construction, with the wire-eroded body assembled to a low grade steel base. With the development of taper cutting, the opportunities for PM tools increased to include tapered leads at the top of dies, tapered core rods and tapered punch bores. The same was true of electrode manufacture with the use of tapered forms in copper plate, as used for female or reverse erosion. The principle of EDM was literally turned on its head.

Today, the optimisation of WEDM is almost fulfilled but there are some areas remaining where wire-erosion can be applied to extend tool life and increase efficiency.

Fig. 7 A workholding reference system is needed to ensure precision location (Courtesy Erowa)

<u>Advantages of WEDM machining:</u>

- Ideal for dies, punch bores and core rods
- Manufacture of tapered electrodes for EDM
- Complex profiles can be machined to very tight tolerances.

Fig. 8 The modern use of workholding has extended to complete press adaptors and palletisation (Courtesy System 3R)

Fig. 9 Tools are designed and manufactured with an inbuilt reference system that remains in place throughout tool production and transfers to the pressing tool adapter (Courtesy System 3R)

Workholding and reference systems

The introduction of standardised workholding and reference systems revolutionised the toolmaking industry. Initially limited to a system based on precision 20 mm diameter mandrels to enable standardised manufacture and use of EDM electrodes, the modern use of workholding has extended to complete press adapters and tool palletisation [Fig. 8]. The main suppliers of workholding systems are Erowa, Hirschmann and System 3R, all of which offer similar systems based on their own individual design.

Historically, setups for toolmaking were often time consuming and in some cases took longer than the actual machining time of the operation. Reference systems provide repeated accuracy from just one initial setup, loading of subsequent parts is a quick and simple operation taking just seconds to complete but ensuring the same precision location. The introduction of a reference system into tool production, by means of fitting special workholding chucks onto all machines, greatly reduces setup times and increases the accuracy of all machining activities. This is best demonstrated in EDM when electrode production and tool manufacture are viewed as a single production flow.

For some applications the tools are designed and manufactured with an in-built reference system that remains in place throughout tool production and transfers to the pressing tool adapter. This type of system can reduce press setting times from hours to minutes [Fig. 9].

PM tool materials

Tool steels

The development of advanced manufacturing techniques now provides a range of Particle Metallurgy tool steels that are made using the Particle Metallurgy process. These PM steels, as they are known, offer a greater choice of tool material compared to the traditional D2 alloy steel or tungsten carbide (WC) alternative. However, acceptance of these new steels has been slow and some PM companies are reluctant to change from the old conventional D2 tool steels to the modern high performance tool steels offered by Erasteel (ASP steels) and Crucible* (CPM* steels), for example. The advanced processing of these tool steels benefits the tool user by offering improved tooling performance in terms of superior wear resistance and increased toughness. Tool steel costs do not generally exceed 10% of the total manufacture cost of the tool and the higher material cost is easily recovered in terms of extended tool life.

When analysing tool failures, one common misunderstanding lies in the properties of steel in terms of hardness, toughness and wear resistance. An understanding of these different properties is necessary before identifying the failure and proposing any corrective action. The basic explanations of hardness, toughness and wear resistance given below are for guidance and it is recommended that contact is made with the steel supplier for assistance with specific applications.

Hardness

Hardness of steel is defined as a measure of resistance to deformation, compression or indentation [1]. The resistance is measured using a hardness tester which measures the indentation made by a diamond cone at a given load and usually expressed as Hardness Rockwell Scale C (HRc). Hardness testing is measured directly on the tool, after heat treatment and before finish machining.

Tools which suffer deformation generally possess insufficient hardness, typically evident in the deformation of punch faces and indenting of die surfaces. Resistance to indentation is directly related to the hardness and not the steel grade. Therefore, when the same indentation size is measured in different grades, it is because they have the same comparative hardness. Corrective actions for deformation may include increasing hardness, modifying the tool geometry or decreasing operating loads. Using different steels will not overcome the deformation unless the substitute can be used at a higher hardness.

Toughness

Toughness of tool steels is defined as the relative resistance of a material to breakage, chipping, or cracking under impact or stress [1]. Different methods are used for toughness testing, typically Charpy C-Notch and Izod sudden impact tests, or fracture tests which use a gradually applied load as opposed to a sudden impact. The destructive nature of the testing means that it is not possible to measure toughness directly on the tool and the preparation of test pieces is required for analysis. Due to the differing nature of the test methods, the comparison of results is difficult.

Tool failures due to lack of toughness are difficult to predict and often result in the breakage of the tooling element or, in extreme cases, the complete tool. Toughness failures highlight the need for tool optimisation. Only through careful tool design and controlled manufacture is it possible to reduce the failure factor usually arising from inadequate heat treatment, poor surface finish, EDM residual white layer or tooling misalignment.

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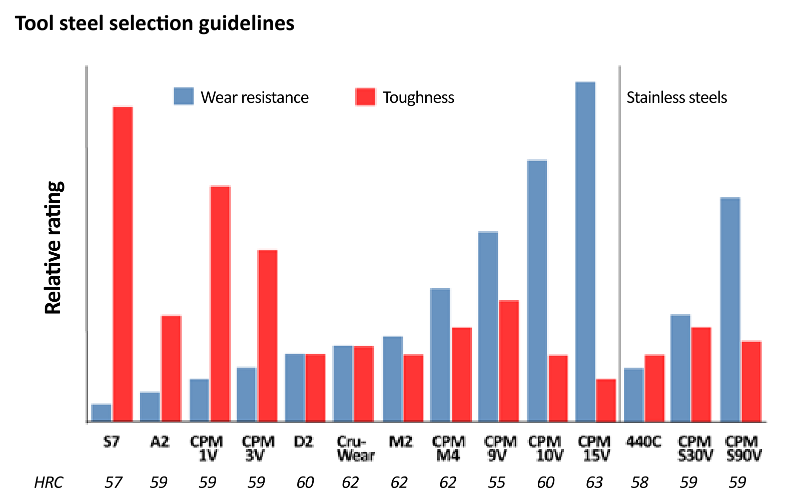

CHEMISTRY	CPM 1V	CPM 3V	CPM M4	CPM 9V	CPM 10V	CPM 15V	CPM S30V	CPM S90V
Carbon	0.55%	0.80%	1.45%	1.90%	2.45%	3.40%	1.45%	2.30%
Chromium	4.50%	7.50%	4.00%	5.25%	5.25%	5.25%	14.0%	14.0%
Vanadium	1.00%	2.75%	4.00%	9.00%	9.75%	14.5%	4.0%	9.0%
Molybdenum	2.75%	1.30%	5.25%	1.30%	1.30%	1.30%	2.0%	1.0%
Tungsten	2.15%	-	5.50%	-	-	-	-	-

Fig. 10 Most steel manufacturers provide excellent comparative charts to aid material selection (Courtesy Crucible Industries)

Wear resistance

Wear resistance is defined as the ability of steel to resist abrasion or wear caused by friction resulting from contact with work material or other tools. Wear resistance is provided by both the hardness and chemistry of the tool [1]. Wear tests are designed to replicate environmental conditions of the tool during the specific process.

There are many types of wear but the two types mainly causing damage to PM tools are abrasive and adhesive wear. Abrasive wear usually results in the rounding of edges, as from abrasive powder or metal particles and does not require high pressures. Adhesive wear is usually caused by frictional contact between two surfaces, such as between die and punches, punch and punch or core rod and punch. The wear often occurs during high pressure frictional contact and can result in the galling of tool surfaces. Wear resistance of tools will vary with different steel grades and is not directly related to hardness. The use of higher grade steels at lower hardness can often outperform lower grades with higher hardness. Most steel manufactures provide excellent comparative charts to aid material selection [Fig. 10].

Tungsten Carbide (WC)

Often referred to as hardmetal or simply carbide, this material type is a metal matrix composite where tungsten carbide particles are the aggregate and metallic cobalt usually serves as the matrix. One misconception of carbide is that it is a material comprising one grade. This is commonly demonstrated on tool drawings where the designer will specify carbide rather than a specific grade. This is similar to simply specifying steel for a punch material, something one would not imagine happening. The properties of tungsten carbide are typically controlled by three factors; grain size, hardness and percentage binder, where on specifying any two factors the third will naturally be defined. Thus, 3% binder content will give a material with very high hardness, high wear and abrasive resistance but low resistance to shock or impact. Alternatively, 30% binder content will give a material with low hardness, high toughness and high resistance to shock or impact. Grade choice can vary depending on the application, and also depends on whether the element is a die, punch, core rod or ejector pin.

When designing carbide tooling the material's unique properties must always be considered. Given its high compressive strength, carbide is ideal for die inserts and, like steel, it can be easily assembled using shrink fitting techniques. One situation best avoided, however, is where the material is subjected to shock loading, as in the stepped or shelf die design. This situation can be overcome by the use of a straight through die form and multiple lower punches. The multiple lower punch assembly also allows more adjustment of fill depth and aids ejection of the PM part.

Punch and core rod designs often use either a brazed or mechanical assembly. Brazing of carbide can be achieved with the correct techniques and selection of suitable grades. Selection of the preferred grades, correct pre–heating and specific brazing alloy will provide a good bond. Given the different expansion coefficients of steel and carbide, the use of copper based tri-foil is necessary to provide a laminate joint fixing for punch faces. Common mechanical assembly techniques for PM tool applications comprise retaining plates, as used for die assembly, and screw retaining for core rod assemblies. The development of structural adhesives has increased their usage for engineering applications. However, the demands of PM pressing are such that adhesives rarely provide a suitable alternative to conventional assembly methods.

Surface coatings

Surface coatings can be applied to dies, punches and core rods to increase the surface hardness and reduce friction. Applying a surface coating can increase wear resistance, increase corrosion resistance and improve powder flow during the compaction phase [Fig. 11]. Coating thickness ranges from 2 to 6 microns and are usually applied using the PVD (Physical Vapour Deposition) or CVD (Chemical Vapour Deposition) processes.

Common coatings are TiN (Titanium Nitride), TiCN (Titanium Carbo-Nitride), CrN (Chromium Nitride) and TiAlN (Titanium Aluminium Nitride). When refacing punches, depending on the coating type, the previous coating should be removed to avoid problems caused by delamination of the coating.

Two coatings of differing colours (TiAlN+TiN) are sometimes used to provide an indication of wear. The tool is removed and re-coated before the wear reaches the substrate material. When heat treating the tool it is important to inform the supplier that coating will be applied to the finished tool, as the correct processing temperatures must be used to avoid softening during the coating process.

Fig. 11 Applying a surface coating can increase wear resistance, increase corrosion resistance and improve powder flow during the compaction phase (Courtesy Mechworx Ltd)

Tool design

PM tool design based on the skilled draughtsman imparting his skill onto the drawing board is now surpassed by the computer generated 3D model from which production drawings are extracted. The 3D model can also be post processed to generate the machining program for use on the latest CNC machines. The tooling industry has embraced the latest technology and applied it to great advantage.

However, no matter how advanced the tool design and manufacturing processes, the designer has to start with similar basic principles. By this stage one can assume that the important discussions with the customer about part design, function, cost, lead-time and quality of tooling are already concluded.

Starting with the component drawing and assuming it was already designed for the PM process rather than transferred from the cut steel route, the main considerations are:

- Required material (powder)
- Required density
- Press size
- Number of pressing levels, usually determined by component complexity
- Production cycle, single pressing or compaction and sizing
- Cold or warm compaction
- Secondary machining.

Press type, for example, electric, hydraulic or mechanical has little influence on tool design, as tool size is approximately the same for each type. The major difference will be in the adapters and clamp rings as they differ for each press type. A more critical factor is press tonnage, as the tool needs to be more resistant to breakage and deformation as the tonnage increases.

The difference in tool configuration is based on the part's requirement and press capability, for example multi-level, closed or open loop press, warm compaction and die wall lubrication. Warm compaction requires strategically placed heaters and thermocouples in the press and tooling with sufficient heat capacity to maintain the powder temperature into the die cavity. The difficulty in maintaining the powder temperature increases with larger parts.

Tool materials vary for each PM company and are usually based on what is historically known to produce an acceptable part at the most economical price. However, as few companies run comparative tests on alternative materials, most will be unaware of the advantages of the steel suppliers' latest offerings. Some PM companies specify a material that will provide the longest possible tool life, whereas others take the view that the tool will break before it wears out. In the latter case, unless the powder is highly abrasive

"...as few companies run comparative tests on alternative materials, most will be unaware of the advantages of the steel suppliers' latest offerings"

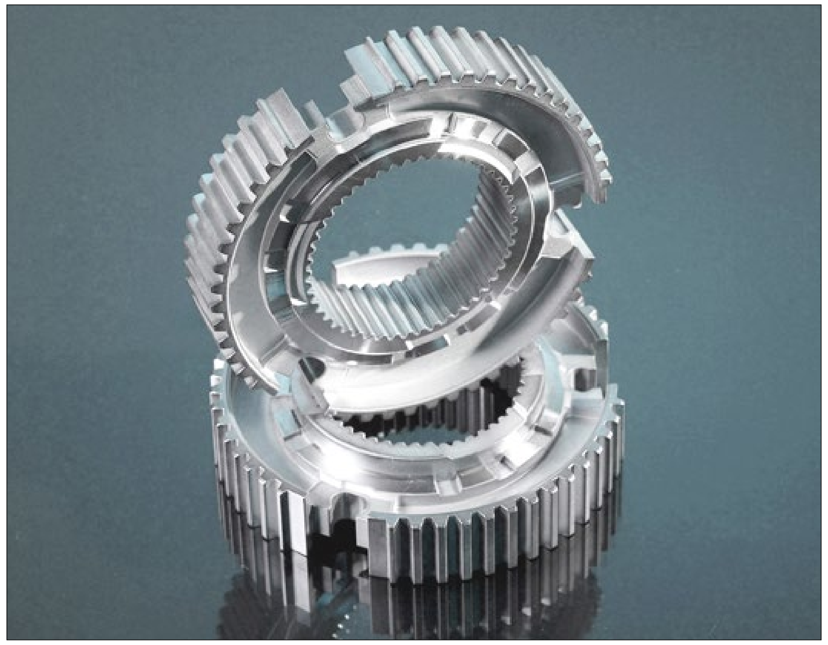

Fig. 12 Advanced pressing technology allows even more complex parts to be produced such as this automotive synchroniser hub. The five-level part made by PMG Group received a MPIF Award of Distinction in 2012 (Courtesy MPIF)

"...only part feasibility and process stability is an argument for adding machining operations. The net shape part is preferred even if the tool investment is high and the tool is complex."

or the part requires a high surface finish, the cheaper material is specified with the reasonable expectation of producing approximately 200 to 300 thousand parts.

Tool costs are generally determined by the complexity of the part, although in some cases this is offset by the avoidance of secondary operations. There is an argument for simpler tooling that may result in more secondary machining of a PM part against more complex tooling that produces a more net shape part. Complex tools are expensive and result in longer lead-times. However, the original advantage of the PM process was the ability to produce near net shapes on reasonably complex parts with tight tolerances and without the need for secondary operations.

As PM technology and know-how has developed, customers have designed more complex shapes and PM companies have invested heavily in high tech machining and in-house finishing processes to satisfy the needs of the customer.

A well-designed PM part offers large benefits in terms of reduced scrap material when compared against a fully machined wrought material. Advanced pressing technology allows even more complex parts to be produced. A case in point would be an automotive synchroniser hub, originally made as a near net shape blank and lightly machined to save on scrap costs, thus producing a cost saving over wrought material. Many of these are now pressed to net shape with a direct saving over the original sintered part (Fig. 12).

In summary, only part feasibility and process stability is an argument for adding machining operations. The net shape part is preferred even if the tool investment is high and the tool is complex.

Tool failure

As can be imagined, tool failure is a sensitive subject for the supplier and end user. Its very existence is often viewed as a personal failure for the parties involved. Though openly discussed within the confines of a private meeting, it is a refreshing experience to discuss it in an open forum.

The fact is that PM tools are complex items made from exotic steels and used in demanding environments. Given these factors it is hardly surprising that failures happen. Albeit a costly exercise it presents the opportunity for knowledge growth and development.

There are many reasons for tool failure and this often results in a finger pointing exercise, with each party rigorously defending their position. This article is not the platform for apportioning blame, and therefore it is more practical to discuss some of the reasons for tool failure. The types of breakages include chipped or broken punch faces, cracked die, bent or snapped core rods and in some cases punches that are completely destroyed. There are just as many, if not more causes. There can be poor tool design, material selection, incorrect heat treatment, poor machining, material fatigue or wear, lack of tool maintenance and general lack of care when handling or setting.

Some companies do not give enough consideration to the safe handling, use and storage of tools. Tools are sometimes stored in open boxes, resting together without any protection of the working surfaces.

Tool monitoring and post-pressing procedures

All data are useful and performance, grade usage and operations should be monitored and logged. Data collection and monitoring of PM tools is necessary to achieve full optimisation of tool usage and continuity of PM part production.

On receipt of a new tooling element or complete assembly, each element should be assigned and marked with a unique identification number. A simple database containing data such as; supplier, date of receipt, production usage, quantity of parts produced, date of reface (for punch) and date of surface coating etc., should record every event of the element until its life has expired. This may seem a somewhat onerous task, given the number of stocked tooling elements, but it provides an invaluable reference for predicting tool life.

Eventually, an historical reference of the expected life and number of parts produced from each tool will be readily available to all personnel. At the very least it will provide an inventory of all tooling and determine if the element is in stock, in production, being re-faced or out for surface coating. This is particularly useful when scheduling production of PM parts, whereby the production planner can estimate the number of parts to be made with the available tooling and therefore the additional tooling required to complete the production run.

Once a tool is removed from the press, it should be thoroughly cleaned and lightly polished to remove any powder debris or process scuffing. Following a visual inspection to determine the tool condition the required data is then logged into the tooling database.

Finally the tool should be either coated with a suitable rust inhibitor and packed for storing, or sent out for re-facing. Good tool housekeeping procedures are essential to producing good PM parts.

Conclusion

The key to making successful PM parts begins with good co-design input between the customer and supplier to ensure the part is designed for the PM process. This is followed by tools that are designed for manufacture and optimised to avoid premature failure and maximise efficiency. It is hoped this article has removed some of the mystery that surrounds this specialised industry, and that the reader can apply some of the principles discussed to their own processes.

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Acknowledgements

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References

[1] Crucible Steel (2007) Tool Steel and Specialty Alloy Selector 2nd ed. New York, pp2-6

Powder Metallurgy gears: Opportunities for enhancing automotive transmission design

It has been the goal of many in recent years to apply the benefits of Powder Metallurgy (PM) technology to the production of automotive transmission gears. As those in the PM industry know, PM offers many advantages in the design of gears, however the key to its success is in convincing those in the automotive industry of these advantages. In a move to demonstrate that PM has the potential for adoption by gearbox designers, engineers at Höganäs AB have for a number of years been road testing a variety of PM gears in real world situations. Anders Flodin, Manager of Gear Technology at Höganäs explains the current state of PM gear design and outlines what is required to break into this potentially very rewarding application area.

Powder Metallurgy gear technology is discussed in this article from the perspective of the gear designer, rather than that of the material designer. Despite this, even the gear designer has to pay some attention to the material he or she is designing with. The material durability will give the allowable stress levels and is paramount when deriving parameters such as tooth face width and helix angle, which in their turn set the contact ratio.

The first hurdle to overcome is identifying where a gear designer can find reliable material data applicable to gear design. The internet will send the designer to the PM Property Database (www.pmdatabase.com), and once registered the user may browse the data. However, there is very little data for rolling contact fatigue. The data that is there is not usable since it is only a value, no information on how the data was generated is included therefore making it impossible to recalculate data to the 95% or 99% confidence levels that are normal for gear design. The values are also extremely high, starting at 1720 MPa with the maximum value of 3000 MPa! Which part supplier can guarantee these numbers? This lack of reliable information will unfortunately

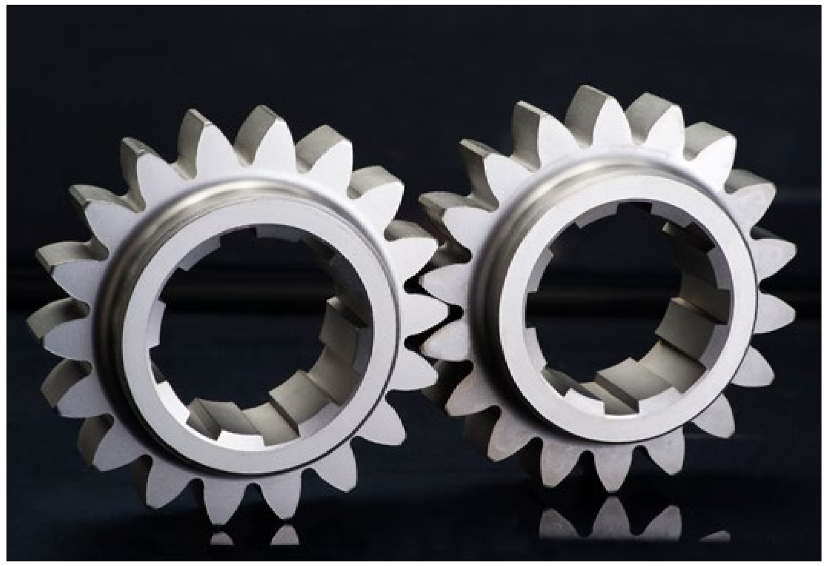


Fig. 1 Powder Metallurgy manual transmission gears developed by Höganäs

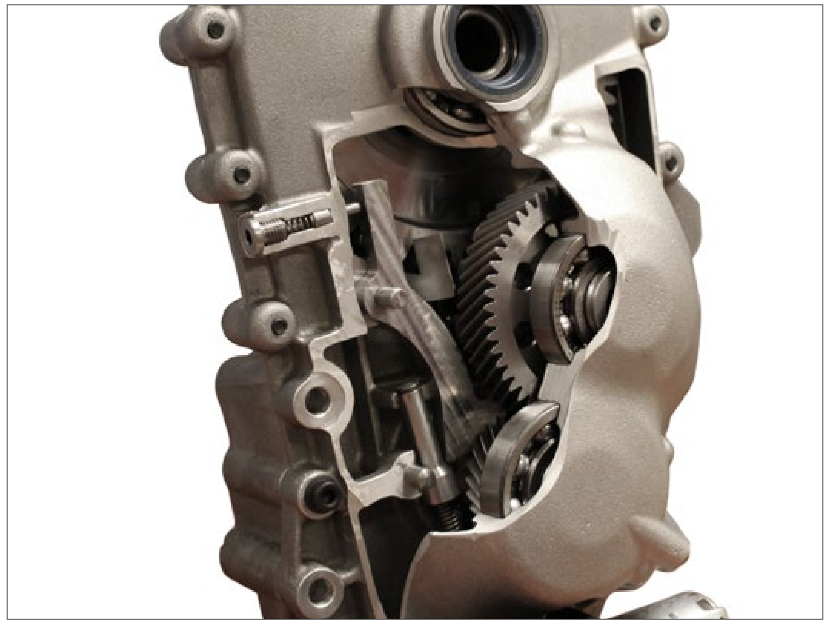


Fig. 2 Prototype transmission for e-car with PM gears in all gear stages as well as for the parking gear and pawl. PM is suitable for noise, vibration and harshness reasons. Since no IC engine is masking the transmission noise, the designer increases tooth face width to reduce noise and lower stresses.

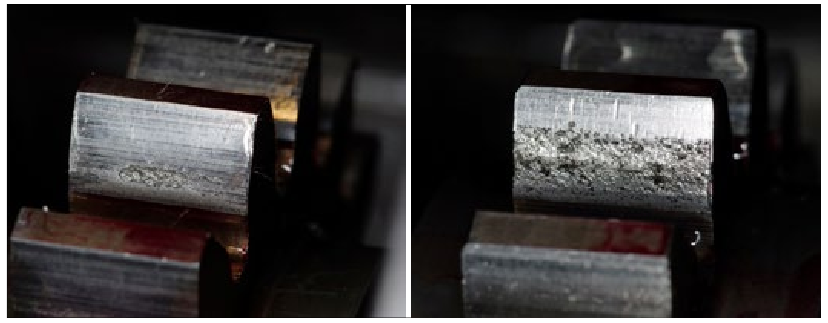


Fig. 3 Different failure mechanisms, both runout. Root cause: Case properties

send any gear designer back to the comfort zone of solid steel. So, how can PM break into the gear market when gear proven data is not readily available? There is no single or simple answer, but reliable fatigue gear data and someone that can deliver gears meeting the data is the first step.

Another hurdle is that for traditional gear design and manufacturing there are three key players;

- The designer (as mentioned above)
- The process planning engineer
- The production engineer.

The roles of these engineers will be quite different and their skill set will have to be expanded when working with PM gears.

Material testing for gear design and manufacture

Gear technology with powder metallurgy normally requires different practices compared to working with solid steel. Micro design is different, macro design can be made more efficient, heat treatment parameters are different, many of the process steps are completely different and the list goes on. The most important piece of data for the design engineer is the fatigue data.

How many load cycles can a PM gear that has been manufactured with a specific process (for example density, carbon level, pore morphology etc.) endure? What is the slope of the S-N curve? Let's then add the complexity of spectrum loads and impact loads and not much, if any, data is available.

Can data from different types of standardised fatigue tests be used? The answer depends on who is answering but to minimise the amount of very expensive gear box testing that has to be done on the prototype transmission, good data and experience from previous transmission tests helps to eliminate unpleasant surprises in later full system rig tests or road trials. The availability of test data and experience from previous transmission development programs within the OEMs lays the foundation for the next generation of transmissions.

When asked the question "What does the design process look like?" an experienced (now retired) design manager from a well known company answered, "We take an old transmission that we know works well and try and change it as little as possible."

With that in mind, it is fair to state that transmission design is conservative which makes it difficult for new technologies to make inroads.

Tooth root bending fatigue

For PM gears, good correlation has been achieved between bending fatigue testing of gear teeth and bending fatigue of test bars, for gear modulus 1-3 mm. So for tooth root bending fatigue, reliable test data from bars can be accepted. Andersson has shown very good accuracy in predicting failure using data from test bars [1].

For a case carburised, quenched and tempered material Andersson was off by only 1.4% in his failure load prediction. Another fact that justifies the use of test bar data is that when designing automotive transmissions it is more common that the critical failure mode is pitting rather than teeth snapping off at the root. Or in other words, the safety margin against tooth root breakage tends to be a little higher compared to pitting. So if there are a few degrees difference in the fatigue limit between test bars and gear teeth it can be absorbed in the greater safety margin.

Pitting

When it comes to pitting there is no substitute for gear pitting tests. Different roller test rigs tend to overestimate the fatigue life and the gears fail prematurely when using fatigue data from roller and disc rigs. Why this is the case depends on several factors such as surface texture, varying slip, wear on the gear flanks, dynamics, boundary effects, misalignments, stressed volume effects, non-representative heat treatment, unaccounted system deformation etc. Lawcock has described this in greater detail [2].

To be able to get the most out of the calculations and also to mitigate risk, gear pitting durability data is preferred and for most gear designers paramount. "Recall" is a word that no auto manufacturer wants in their vocabulary.

Pitting data is difficult to generate as different back-to-back gear testing machines give different results. Interpreting and quantifying the run out criteria is operator dependent which is another source of discrepancy. There are systems that monitor both vibrations [3, 4] and particles in the oil [4] in order to determine pitting and to a certain extent eliminate operator dependency, but at the end of the day visual inspection is needed.

For PM gears it is not always easy to determine the failure type. Pitting in PM gears may look very different from, and it may also look very similar to, solid steel type pitting. Is it still a pitting failure? An example of pitting can be seen in Fig. 3.

Another factor in pitting testing of PM gears is the quality of the heat treatment. For automotive transmission gears the most common type of heat treatment used is the Carburise, Quench and Temper process (CQT). Due to the nature of the PM material, with its pore structure, carbon diffusion rates may vary significantly between different densities. A 7.55 g/cm^3 gear may be carburised using the same formula as a solid steel gear with similar modulus while a 7.25 g/cm^3 gear requires a completely different formula. Additionally the alloying elements play a role, so differently alloyed PM materials at the same density benefit from tailored CQT processes and will add to the confusion for the three key engineers mentioned previously, since they need to understand how to process the gears to get a certain hardness and performance.

"Pitting data is difficult to generate as different back-to-back gear testing machines give different results"

Understanding hardness

Hardness has to be dealt with separately. Hardness specifications on gear drawings for solid steel gears cannot be met with PM material and it is essential to explain to designers that their normal hardness values should not be specified in the drawing but instead he should

Data Sheet:

Astaloy85Mo+0.25%C

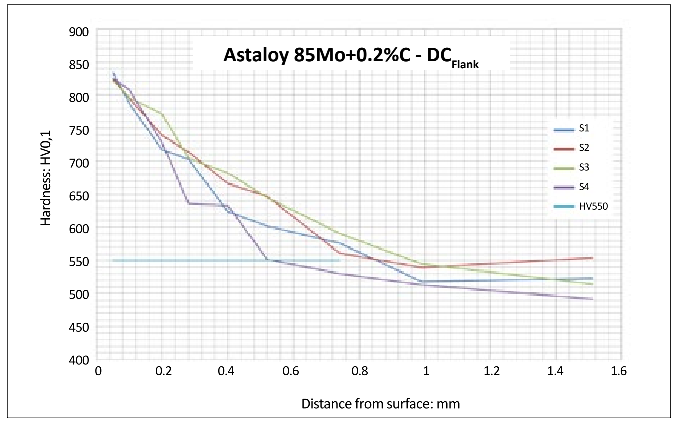
ρ:7.2g/cm³ - mn:1.58 - Machined

Material Composition:	Astaloy 85Mo+0.2%C
Density(g/cm³):	7.25
Csint(%)	
Suface:	Machined
Surface:	Not Ground
Module (mn):	1.58
Eht *min/max*	

Sample: HB gear

Sample	Carburizing (Step 1)			Carburizing (Step 2)			Cool		Quenching	Tempering	
	Temp [C]	Cp %	Time [min]	Temp [C]	Cp %	Time	Temp [C]	Cp%	Oil 60C	Time [min]	Temp [C]
S1	950	1	10				850	0.8	Yes	30	180
S2	950	1	15				850	0.8	Yes	30	180
S3	950	1	20				850	0.8	Yes	30	180
S4	950	1.2	10				850	0.8	Yes	30	180

Case hardening parameters



Sample	Surface Hardness	Hardness 0.3 mm from surface	550 HV	KHR
S1	834	703	0.85	450
S2	825	714	0.9	440
S3	822	705	1	470
S4	826	636	0.5	

Results

Fig. 4 Data sheet for case hardening

use micro hardness. Manufacturing engineers have to teach their team to measure hardness differently as well.

Fig. 4 shows a data sheet for case hardening evaluation, there are 16 different variables defining material and process. The number of variants is simply overwhelming so attention has to be paid to the design of the experiments to create a map of the most influential factors. In order to avoid spending time and money in the prototyping phase on CQT trials of the gears it is of great help to be able to pin-point the right CQT process for the specific gear modulus, material composition and manufacturing process both pre- and post CQT.

This know-how is important to the process planner and manufacturing engineer. It is also important that the engineer tuning the CQT furnace to the needs of PM is fully informed, not only by a piece of paper with the formula, but also the definition of each of the process parameters and a clear understanding of the consequences if the formula is not followed. The interpretation of a formula can vary greatly and sometimes be completely ignored with underperforming and failing gears. This scenario happens too often and is totally detrimental to OEM gear programs, giving the material a bad reputation when the problem lies in the process.

Prototyping

In the process of prototyping automotive gears for OEMs, the fatigue data used by the designer has to be relevant to the combination of material composition, density and CQT formula that will actually be used to make the prototyped gears. If this is not the case, the fatigue data is of little use for any serious life prediction models and more testing is required than would have been necessary if data was available.

A question from the OEMs that is sometimes asked is whether a compacted gear wheel from a PM tool, if manufactured correctly, will match a hobbed and ground PM gear made from a slug in terms of durability? The answer to this is that, when moving from prototypes to procedures closely representing serial production with proper tooling and press settings, no hidden surprises have to show up. Of course proper crack control and density distribution checks should be performed during compaction trials and any issues should be addressed but there is experience in the PM industry today that supports this claim, though unfortunately references cannot be given due to non-disclosure agreements.

PM gear process routes

This is where the traditional gear manufacturing engineers and process planners have to get out of their comfort zone and learn the PM methods of making gears. The reason for this is because they most likely will have to do the final machining of the gears in order to meet the tolerances. So they need to know the expected heat treatment distortion, tolerances of the parts before heat treatment, definition of the lead-in of the protuberance (angle, start radius etc), suitable reference plane, grinding data to avoid burns, everything that is needed to clamp the gears and hard machine them to desired quality.

There are many ways to make a PM gear, more than will be touched upon in this article. The trick is to make a gear that fulfils the following three criteria:

- Cost effective
- Performs according to designed service life
- Robust in performance.

Cost effectiveness

In order to fulfil the cost effectiveness requirement an analysis has to be done of current manufacturing cost and then compare with an honest cost calculation of the PM route. It is always sensitive and difficult to do this since few will reveal the actual cost for their produced gears. One rare example was presented by Dr Strehl of Getrag Ford at the Aachen Gear Seminar in November 28-29, 2012 and also an updated version by Dr Rochlitz from Getrag Ford at the Power of Powder seminar in Höganäs Sweden September 18, 2013. Their study showed that PM can meet the cost criteria, and when looking at investment cost when building a new plant, PM has the potential to reduce that cost significantly.

"Their study showed that PM can meet the cost criteria, and when looking at investment cost when building a new plant, PM has the potential to reduce that cost significantly"

When these calculation exercises are done, PM very often comes out as the more attractive alternative, but not every time. The automotive industry is said to be the most competitive industry in the world and many of the manufacturing philosophies to lower cost or increase quality, whatever buzzwords we choose to name them by, spawn from the automotive industry. So the machining of gears has become highly effective and competitive. There are three keys for PM gears to win this and those are:

- Avoid soft machining
- Avoid as many process steps as possible while still maintaining robustness and durability
- Chances to win on cost increase when including investment costs in total cost model.

Surface densification

Today most PM gear companies working with OEMs on transmission gears employ some form of surface densification or even forging. This, of course, eats into the margins but adds extra safety. The ideal would be if densification could be omitted if not needed and again this falls back to good fatigue data.

One of the drawbacks of surface densification besides cost is that there are no techniques that will densify both teeth and bore at the same time, so any PM bore that is used as a needle bearing raceway has to be double checked for stress levels. For manual transmissions the loads are not that high on the bore

Roughness parameter	Rolled	Shaved
Ra (μm)	0.12	0.28
Sa (μm)	0.13	0.34

Table 1 Roughness parameters

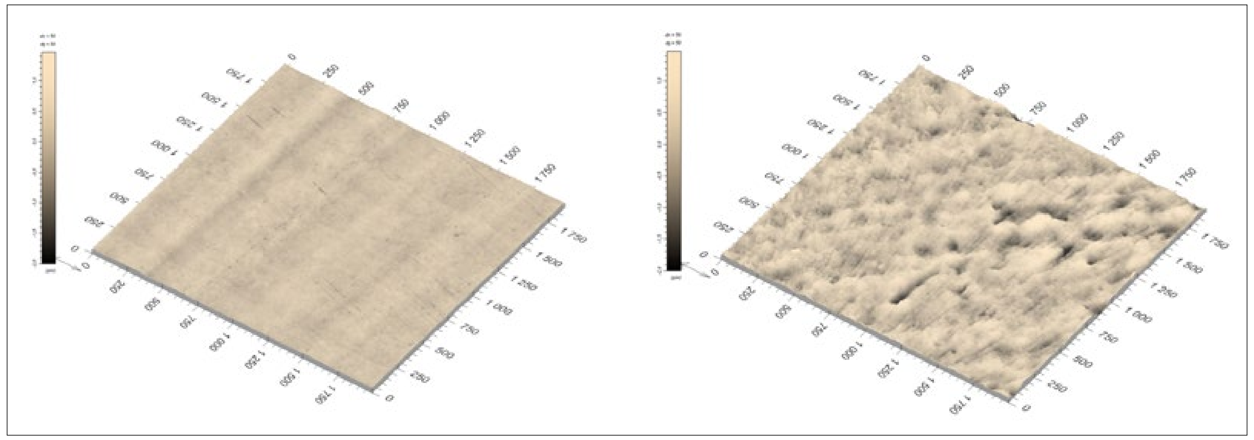


Fig. 5 3D topography scans of rolled gear (left) and shaved gear (right)

Fig. 6 Back-to-back gear tester

Process	TRBF (MPa)	Pitting (MPa)
Compaction-Sinter-CQT-Grind	650	1050

Table 2 PM gear manufacturing route with run out levels (P=95%)

Fig. 7 Smart Fortwo in Florence for the PM2010 World Congress

when the gear is spinning. When the gears are not spinning, however, the loads can be significant. There is also the misalignment that has to be considered. The gear, when loaded, wants to tilt due to the forces and this creates high contact stresses on the edges of the bearings. On the up side, besides increased strength, is the very smooth and tribologically attractive surface that densification gives. Fig. 5 and Table 1 give roughness parameters.

For planetary gears the contact stress from bearing forces will be just as limiting as the contact stress on the gear teeth, so particular attention has to be paid when working with that type of gear. There are of course ways around this, but are they cost efficient?

The differences in carbon diffusion rates between densified surfaces and non densified surfaces also have to be understood. If not, over carburisation with carbides in certain areas will be present and this affects fatigue life and tool life of the grinding wheel.

A gear that is most interesting for PM is the ring gear in the planetary gear set. Stresses are lower than for the other gears in the system and it is a difficult part to machine to high tolerances and is also relatively costly. For this gear, a roll-burnishing operation would work well with PM since this would introduce crowning and also polish the surfaces and give a surface roughness closer to a super-finished surface roughness (Fig. 5). This type of polished surface tends to give better fatigue properties both in bending and contact and from a gear perspective they are quieter, generally speaking. This is an opportunity for PM to not only be cost effective but also add performance not easily attained by conventional manufacturing.

PM gear performance

Dizdar [5] has compiled an extensive list of pitting data from literature. The problem with this list is that the tests are made in so many different ways that the data is difficult, if not impossible, to compare and make use of. Also the stress numbers are sometimes very odd in this compilation. This exemplifies the problem of obtaining reliable gear data for the designer. Table 2 shows a PM gear manufacturing route with its run out levels.

The data in Table 1 is from internal testing using a Strama back-to-back (FZG) gear tester as well as Vibrophore testing for the Tooth Root Bending Fatigue (TRBF) (Fig. 6). Not all the details defining this testing are given here but the reason for spending the resources to collect the data is purely for PM gear design purposes. The time it takes to run all 40 data points in the FZG rig to create the S-N curve is around 15 months. The data has been verified with the same batch of PM gears in a 100% identical FZG machine at the Royal Institute of Technology (KTH) in Stockholm, Sweden. Having done this work it is possible to reliably design for these types of spur gears with Modulus 4.5 mm. However, for reliable design of smaller modulus gears, for instance 2 mm, this data can serve as a baseline but further tests are necessary to also assure 95% confidence level for smaller module gears.

The numbers in Table 2 are lower than for solid steel gears and this is what should be expected. There are methods available on the market that improve the numbers (densification, see above) and those methods are proprietary to certain PM parts producers, so are not discussed here. Consider the data in Table 2 as the baseline and any densification methods will improve the numbers up to the point of matching solid steel.

The S-N data behind Table 2 will be made available for gear designers through gear design software and this work has already started with Kisssoft that has implemented bending data for the Astaloy 85Mo material.

State of the art PM gears

A number of cars have been prototyped with PM gears in their transmissions to prove that PM works in such applications.

PM gears tested on the road for 145,000 km

The first car was a Smart Fortwo where seven gears were converted into PM and this work was presented at PM2010 World Congress in Florence, Italy.

This car has been on the road since 2009 and collected an impressive 145,000 km without any gear related issues. The engine seized up due to the overheating of the mid-cylinder at 95,000 km so it was completely overhauled for a sum that could not be justified if it were not for the fact that it is a demonstration car with the ambition to see how far the PM gears will work and not how far the engine will work.

A second gearbox was made for a new Smart Fortwo that will run in Brazil. This gearbox is identical to the one that is running in Europe (Fig. 7).

PM gears tested off road for three years

In order to raise the bar a three year rally project was initiated and the Power of Powder Rally Team was formed around an existing rally team led by driver Ramona Karlsson. The team competed with two different transmissions starting off with just the fourth gear pair made via PM in a Mitsubishi Evo 8 (Fig. 8).

This transmission was run for two rally seasons with the same fourth PM gears, the car was replaced with a Mitsubishi EVO 9 for the second season. Meanwhile a new full 100% PM gearbox was designed and prototyped for the more powerful EVO 10 car (640 Nm, 330 HP) that was prepared for the World Rally Championship (WRC). This competition car was shipped around the world and competed until it accidentally caught fire in Rally New Zealand as the team was cruising towards total victory in its class. Unfortunately the transmission was also destroyed in the fire (Fig. 9).

Fig. 8 First generation PM gear equipped rally car

Fig. 9 Power of Powder Rally car in flames and the PM gearbox destroyed. Driver and co-driver stepped out of the car in time, so no casualties

The purpose of these demonstrator cars was to show that PM can be made to work in any application from the less demanding Smart Fortwo all the way to extreme cars such as rally cars. It is just a matter of using the right material, making a good design and using the right processes and by doing so, tailoring the strength of the gears.

A rally car will need some more advanced processing of the gears to withstand the high dynamic loads from jumping and potholes. In the Mitsubishi, HIP (Hot Isostatic Pressing) technology was used to boost performance. As an aside, a non HIP transmission was also tested on Mitsubishi track cars. 1000 km was run with a non-HIP rally car transmission using a track prepared Mitsubishi EVO 8 without any notable wear on the gears at disassembly of transmission.

Six-speed transmission converted to PM

As previously stated, all process steps that can be omitted while maintaining sufficient durability will increase the competitiveness of PM gears. For this reason a design study was started with the S-N data from the back to back and vibrophore testing used as the durability boundary. The idea was to theoretically demonstrate which gears in a bigger car could possibly be manufactured with the shortest possible manufacturing route, thus maximising competitiveness. A SAAB 95 was chosen with its accompanying M32 transmission for redesign (Fig. 10).

Analysing the whole system

The design study should not comprise individual gear sets using an idealised calculation method, but

Fig. 10 The M32 six speed manual transmission is used in the SAAB 95, Opel Insignia, Chevrolet Cruze and a few more GM platforms

Fig. 11 The fourth drive gear, comparing the stock design (left) and PM weight optimised design (right)

the whole system should be analysed in the same manner as automotive transmissions are designed and analysed by the best OEMs and design houses. This includes simulations of:

- Running behaviour at all relevant temperatures
- Bearing deformations
- Housing deformations
- Shaft and gear deformations
- Bolt connections
- Pre loads on bearings
- Stresses and shock loads.

A lighter gearbox
Another aspect of the design study was to investigate how much lighter the gearbox could be made using PM technology while maintaining a low transmission error and keeping contact stress within allowable limits based on a typical European drive cycle that is normal and relevant for the automotive industry. Another idea was to keep the manufacturing chain as short as possible and solve high stress problems using design methods rather than costly processing.

The results might surprise a few; with a bit of ingenuity all gears could be made using PM gear technology. The input torque was set to 320 Nm which is on the high end and with the experience of driving the SAAB it is evident that the engine is torque limited in first, second and reverse so not to break those gears. Stress numbers were also found to be unreasonably high for these gears if using 320Nm as input torque. A few key findings from this study were:

- Gears one, two and reverse can be made using asymmetric gear technology or convoloid to reduce stress and the gears will then be suitable for PM
- Gears three and four can be made using 1P1S to 7.2 g/cm^3
- Gears five and six are borderline for 1P1S so 2P2S is recommended for higher density and endurance needed
- Gears could be made 8-22% lighter (Fig. 11),
- 1.1 kg lighter with PM design in total
- Transmission error can be kept equally low for most gears and most torques
- Pitting is the limiting failure mode for all gears, abuse excluded
- Root optimisation will reduce root stress by up to 30% [6]

The gear on the right in Fig. 11 is net shape, compacted into an optimised geometry taking out 12% of the weight compared to the stock geometry shown on the left. This demonstrates the manufacturability of PM; making this geometry in solid steel would be costly.

Putting it all together
Having done a thorough analysis of the stresses and deformations the prototyping phase begins. The example gear shown in Fig. 11 is made from tooling just to demonstrate the manufacturability of the PM gear concept with all features compacted net shape, except the lead crowning. The rest of the gears are made from slugs except two gears on the input shaft that are cut on the solid steel shaft (Fig. 10). All gears are hard finished for lead crowning and any heat treatment distortions are taken care of with this process, may it be grinding or honing.

One cornerstone in making this transmission operational is to manufacture the clutch cones and synchroniser teeth and then join them. This requires a good welding process and the synchroniser body. There are two ways to solve this, either measure and machine the body out of PM or steel and press fit and weld it to the gear, or buy a spare gear in solid steel and turn away the gear in a lathe and keep only the synchroniser body. Then the body and gear has to be joined by press fit and weld. This takes some consideration to get it right and every gear will have its own unique design and solutions to this problem. Also heat treatment and carbon concentrations in the weld area have to be considered.

Both laser and electron beam (EB) welding of the synchroniser bodies work fine but trials are necessary to tune the parameters. The weld was also tested in a torque test and did not break at 800 Nm which was the maximum the test bench could deliver.

The next step is assembly of the transmission which required shimming of the bearings to avoid axial play as well as tensioning the housing bolts to obtain the housing stiffness that was used in the modelling and then finally mount on the car for driving (Fig. 12). This should be completed by the time of printing this article.

The bench testing of this transmission using the drive cycle spectrum load is a future task as the results from the FZG pitting testing need to be qualified for use with smaller module gears more relevant for automotive transmissions.

Conclusions

PM gears can be made durable and the strength can be tailored to match the steels that are normally used in automotive gear boxes. It is a matter of understanding material, process and design.

Gear relevant and statistically proven fatigue data is missing. There is also a lack of PM knowledge amongst designers, process planers and manufacturing engineers in the gear industry. This has to be addressed and is no small task for technical marketers from the PM community. The generation of reliable data, and gear proven PM parts suppliers delivering the parts matching the data, is also important to mitigate risk.

PM gears have the ability to be cost competitive, especially when the investment costs are considered as well. More PM geared vehicles have to be put on the roads as demonstrators, not only cars but light and heavy trucks as well. Race cars, whether they be rally or Formula 1, are always an eye opener and help improve the rather negative image of PM that is present amongst too many automotive engineers.

The PM industry is also rather small compared to the machining industry and we as an industry need to come together better, growing the market with new applications. This takes a lot of R&D resources and requires a critical mass to be able to be supported financially; even more reason to work as a team.

Fig. 12 SAAB 95 with prototyped PM 6 speed transmission

"The PM industry is also rather small compared to the machining industry and we as an industry need to come together better, growing the market with new applications."

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References

[1] Andersson, M, Predicting PM gear tooth root bending strength. To be presented at World PM Congress 2014 in Orlando.

[2] Lawcock, R, Rolling Contact Fatigue of Surface Densified PM Gears. *Gear Solutions*. pp.29-43. Oct. (2006).

[3] Ozevin et. Al. Damage Assessment of Gearbox Operating In High Noisy Environment Using Waveform Streaming Approach. *J. Acoustic Emission*, 25. pp.355-363. (2007)

[4] Dempsey, P. A Comparison of Vibration and Oil Debris Gear Damage Detection Methods Applied to Pitting Damage. NASA / TM--2000-210371.

[5]Dizdar, S. Pitting resistance of small-module gears. Proc. IMechE Part J: *Engineering Tribology*. 227(11) pp1225-1240 (2013)

[6] Andersson, M. Flodin, A. Optimizing the Tooth Root Strength of Sintered Gears for a Manual Automotive Transmission. Proceedings EuroPM 2013.

Powder Metallurgy's new frontier: Thermoelectric materials for the energy harvesting revolution

Major car producers are working to turn waste heat from engines and exhausts into electricity using newly developed thermoelectric alloys. These alloys can help power the vehicles' electrical systems and improve fuel efficiency. Waste heat from industrial sources such as furnaces can also be recovered to produce electricity using thermoelectric devices. Bernard Williams, a Consulting Editor of *Powder Metallurgy Review*, takes a look at some of the ongoing developments using Powder Metallurgy technology to produce a new generation of sintered thermoelectric alloys.

The bulk of the world's electricity is generated by heat energy, of which around 60% is waste heat lost to the environment during the conversion process. Huge amounts of waste heat are also generated in manufacturing plants and in transportation vehicles. For example, internal combustion (IC) engines in vehicles capture only 20-25% of the energy released during fuel combustion with waste heat being emitted through the engine, exhaust and the coolant radiator. Thermoelectric materials and devices could recover some of this waste heat/energy and convert it into useful electricity. The efficiency level of this so-called 'energy harvesting' is, with the present technology and materials, around 7%.

Researchers from around the world have been accelerating their efforts over the past decade to find solutions to recovering and recycling waste heat using a variety of thermoelectric materials to improve recovery efficiency. Examples include oxides, half-Heusler alloys, clathrates, silicides, antimonides and tellurides. Powder Metallurgy (PM) appears to be a key route to processing these newly developed thermoelectric materials, which could be PM's new frontier in the 21st Century.

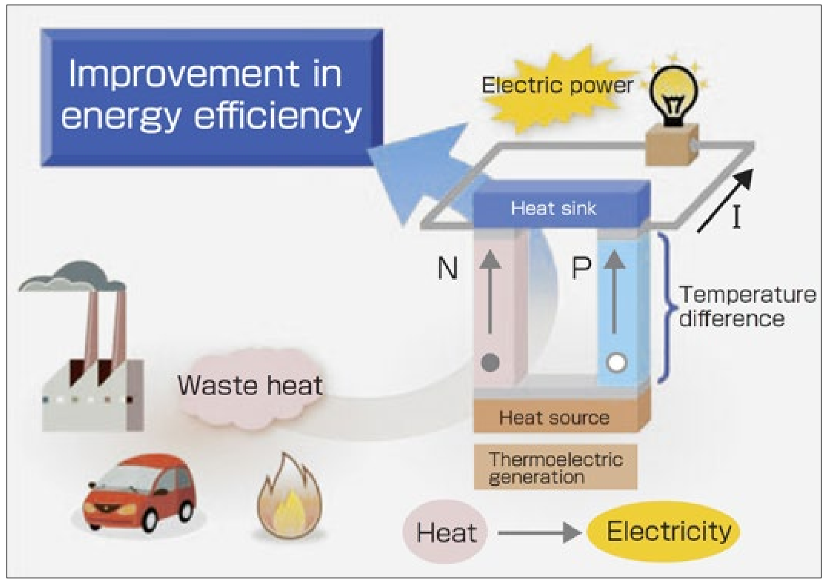

Fig. 1 Concept for waste heat recovery developed at AIST using thermoelectric generation modules [1]

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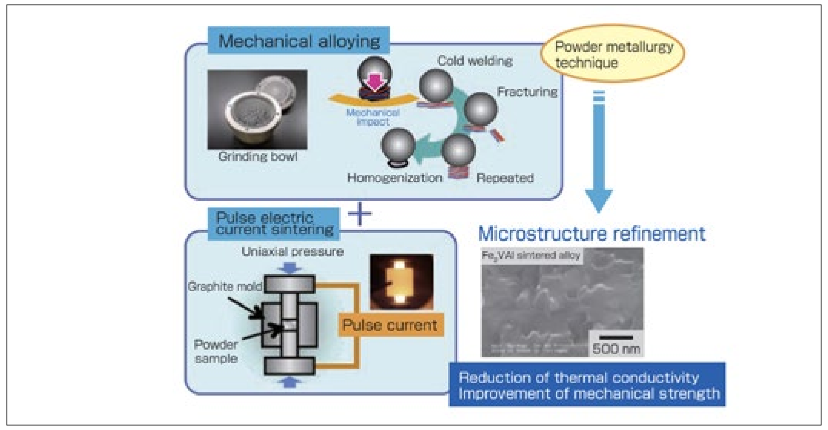

Fig. 2 Powder Metallurgy processing of Fe_2VAl [1]

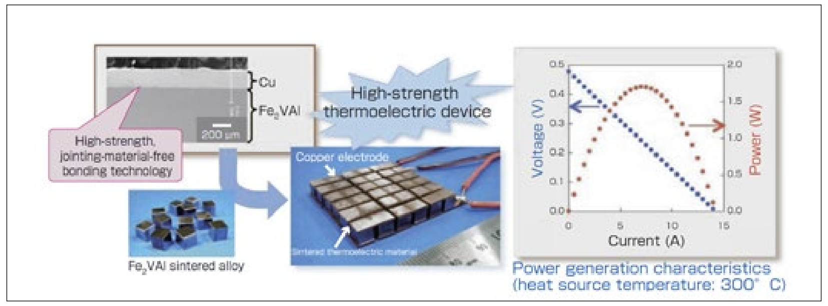

Fig. 3 Fe_2VAl thermoelectric modules and their power generating characteristics [1]

Thermoelectric modules for high temperature environments

The Materials Research Institute for Sustainable Development at the Institute of Advanced Industrial Science and Technology (AIST), Japan, is one of the Japanese organisations involved in the development of thermoelectric materials by the Powder Metallurgy route. Dr Masahi Mikami, who leads the research in this institute, states that most of the waste heat generated is at a relatively low temperature (<200°C), and that this is widely scattered, for example in power plants, factories, vehicles, etc.

The most effective way of converting waste heat is via local thermoelectric generation (TEG) which is said to provide a conversion efficiency independent of the energy scale and should be capable of generating electricity from waste thermal energy of any temperature. A basic system described by Dr Mikami for generating electricity from waste heat is shown in Fig.1 [1]. Here an electric circuit consisting of connections of p-type and n-type thermoelectric materials set up in series can generate electricity when one of the thermoelectric materials is heated up using waste heat. Much attention has been paid to the intermetallic compound of bismuth (Bi) and tellurium (Te) which is a highly effective thermoelectric material for temperatures up to 200°C. Bi-Te thermoelectric devices have been developed having a conversion efficiency of several percent.

The drawback with both Bi and Te is that they are rare metals with high cost and availability issues, raising potential problems. The Bi-Te system is also said to have relatively low oxidation resistance and mechanical strength. AIST has therefore been investigating other thermoelectric alloys with a Heusler crystal structure such as iron-base alloy Fe_2VAl. These alloys are less resource restrictive and lower cost than Bi-Te, have good oxidation resistance and have a high melting point of 1500°C. However, Fe_2VAl has relatively high thermal conductivity making it difficult to obtain a large temperature differential and high energy conversion efficiency.

Dr Mikami stated that this problem was overcome by controlling the microstructure of the Fe_2VAl alloy using Powder Metallurgy techniques. AIST first succeeded in producing nano-sized alloy powders using mechanical alloying (MA) that allow stable repeated milling and mixing (Fig. 2). The MA powder was compacted and rapidly sintered using a pulse-current sintering technique to suppress grain growth with the resulting fine microstructure showing nanometer-order crystal grains in the sintered material. Dr Mikami stated that the PM process was successful in lowering the thermal conductivity of Fe_2VAl through a scattering effect at the grain boundaries. The structural refinement also improved the durability of the Fe_2VAl material by dramatically increasing its mechanical strength.

AIST succeeded in developing a high strength joining technique for the thermoelectric material to the copper electrode, and reports that as much as 1.7W of power can be obtained when used with a heat source of 300°C (Fig. 3). AIST envisages that the newly developed Powder Metallurgy Fe_2VAl thermoelectric device has potential practical applications in harsh environments such as in IC engines, which are subject to vibration and extreme heat cycles.

Hitachi Chemicals Powdered Metals Division in Matsudo-chi, Chiba, Japan, has been working with the Central Research Institute of Electric Power Industry in Tokyo to develop thermoelectric encapsulated modules from SiGe, Mg_2Si, Mn1.8Si and Bi-Te alloys for conversion of heat to electricity at temperatures from 180 to 650°C [2]. The encapsulated TEG modules consist of a vacuum-tight stainless steel container having dimensions 55 mm x 50 mm x 11 mm in which the SiGe elements made by PM were placed (Fig. 4). The interior of the container is maintained in a vacuum following electron beam welding in a vacuum chamber. Mica sheets are used in the container for electrical insulation and carbon sheets are used on both sides of the module to accommodate the differential thermal expansion. It was stated that encapsulation of the TEG modules allows them to be placed in hot air or corrosive atmospheres found in industrial furnaces or automotive exhaust gases. The encapsulated SiGe modules can operate at temperatures up to 650°C for both the hot and the cold sides. Hitachi Chemical has also developed encapsulated BiTe modules having an operating temperature range of 180°C to 190°C for both the hot and cold sides, and is currently developing an encapsulated module using high performance MgSi elements.

The company states that the electrical power output of the encapsulated module is 0.84 times greater than that of non-encapsulated modules. The power of the developed encapsulated SiGe modules indicated 8.4 W where the hot and cold duct side temperatures were 650°C and 20°C respectively. The electricity generating performance of SiGe encapsulated modules is shown in Fig. 5 [3]. The modules were shown to survive 1400 heat cycles without breakage or deterioration when used in a sintering furnace. As a result 5 kW of electricity could be generated when SiGe modules and BiTe modules were installed in the upper and lower side of the furnace cooling zone respectively [4].

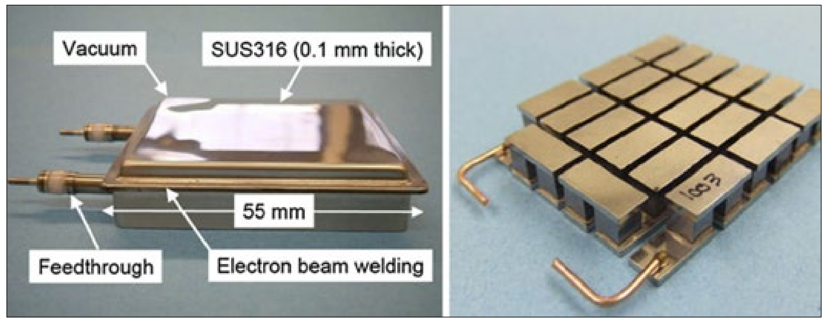

Fig. 4 Encapsulated thermoelectric modules developed by Hitachi Chemical (left: SiGe or BiTe) in which the SiGe module (right) is encased [2]

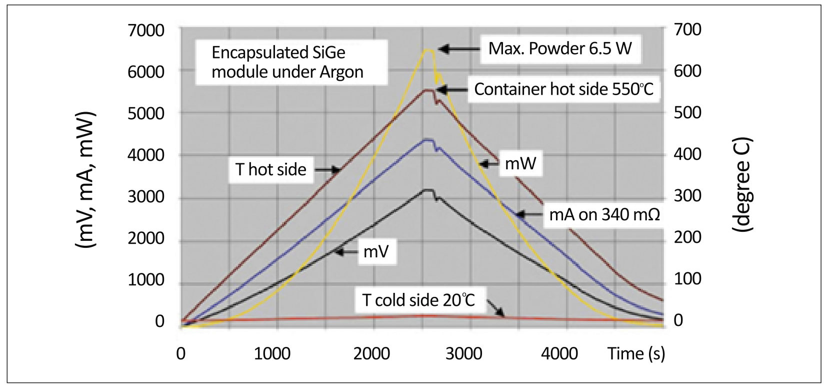

Fig. 5 Electricity generating performance of encapsulated SiGe modules [3]

Waste heat recovery underway in US programmes

In the USA the US Department of Energy's (DOE) Vehicle Technology Program is funding a $12.7 million, four year research program (2011-2015) on 'Nanostructured High Temperature Bulk Thermoelectric Waste Heat Recovery' [5]. The aim of the programme, which is led by GMZ Energy and also involves Robert Bosch, Oak Ridge National Laboratory, Honda, University of Houston, and Boise State University, will be to demonstrate a robust, thermally cyclable thermoelectric exhaust waste heat recovery system that will provide at least a 5% fuel efficiency improvement for a light-duty vehicle platform. A small-displacement engine of approximately 2.0 litres (Honda Accord) will be used to develop the exhaust waste heat recovery system. According to Jonathan D'Angelo at GMZ Energy [6] the project has already resulted in the development of significantly improved nanostructured bulk Bi-Te alloys for the thermoelectric generators which consist of an

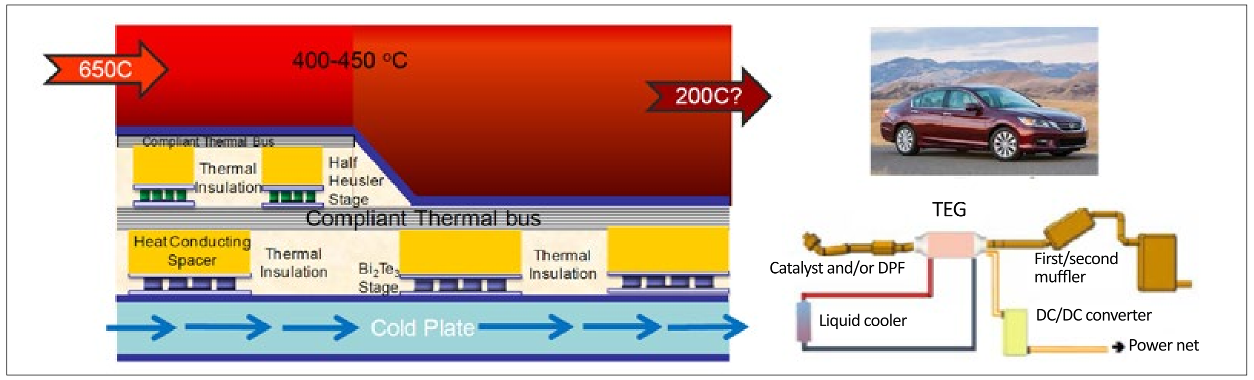

Fig. 6 The GMZ-led US Department of Energy research project is evaluating the cost performance versus electrical of a two-stage thermoelectric generating system [6]

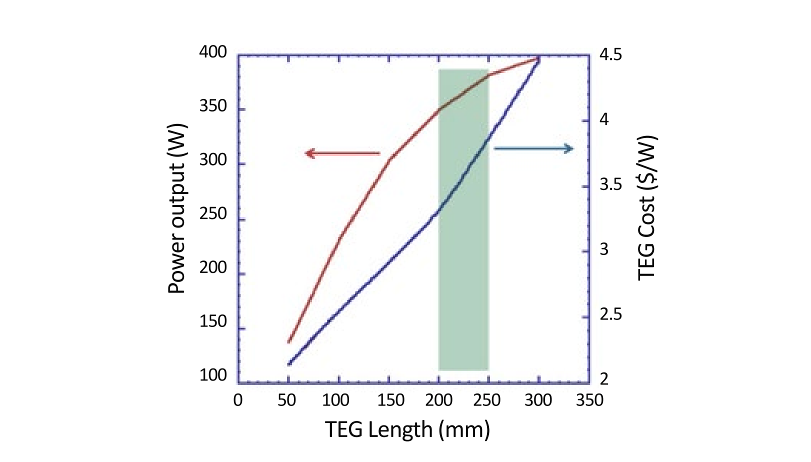

Fig. 7 Initial cost assessment for bulk thermoelectric energy conversion [6]

array of semiconductor elements used in post catalytic converter heat exchangers to remove heat from the exhaust gases and deliver it to the thermoelectric devices, which convert the heat to electricity.

The two-stage TEG system with half-Heusler material as the first stage, and Bi_2Te_3 as the low temperature stage, is shown in Fig. 6. The research team is evaluating the cost performance versus electrical gain of the two-stage approach with work currently underway at GMZ to develop low cost, large volume processes. D'Angelo stated that TEG size should be optimised for power and cost with the optimal size estimated at ~200-250 mm (100 mm x 100 mm cross section) giving a power output close to 400 W (Fig. 7). The initial cost assessment has put complete system cost in the $3.75 to $4 per Watt range, but by reducing hafnium content in the half-Heusler material from 0.75% to 0.25% the project will meet OEM target cost of $3 per Watt without inhibiting performance. Ultimately, after testing and optimisation, the team's goal is to have a plan for scale up and commercial production when the project reaches completion in the summer of 2015.

In another project supported by funding from the US DOE and the National Science Foundation, the Oregon State University (OSU) is using microwave sintering to produce a promising group of thermoelectric alloys called skutterudites for capturing waste heat and turning it into useful electricity. Skutterudites in the form of (Co, Ni, Fe) (P, Sb, As) alloys have the needed properties to convert low grade waste heat into electricity. The researchers, led by Professor Mas Subramanian in the Dept of Materials Science at OSU, recently stated in a report [7] that the previous process used to produce the skutterudites was complex and costly which would take three to four days. Now, using microwave sintering of the indium cobalt antimonite powdered metals at 1800°C, it takes just a few minutes and the researchers expect it to lead to a commercially useful, low-cost path to the future of thermoelectric energy.

"We were surprised this worked so well," Subramanian stated in a report in Science Daily (September 21, 2011). "Right now large-scale thermoelectric generation of electricity is just a good idea that we couldn't make work. In the future it could be huge."

Nanoparticle embedded alloy thermoelectrics (NEAT)

A research project called 'Nanoparticle embedded alloy thermoelectrics' (NEAT) is currently underway with funding by the European Union's FP7 Research Programme [8]. The nine partners from six EU countries aim to develop an innovative bulk alloy nanocomposite capable of attaining ZT>3 at high and medium temperatures by considerably decreasing the material lattice thermal conductivity. The NEAT project focuses on three types of sintered nanocomposites suitable to harvest energy in the kW range:

- Mg_2Si nanoparticles (Fig.8 left) in $Mg_2SiGeSn$ alloy matrix for medium temperature range (500-800K)

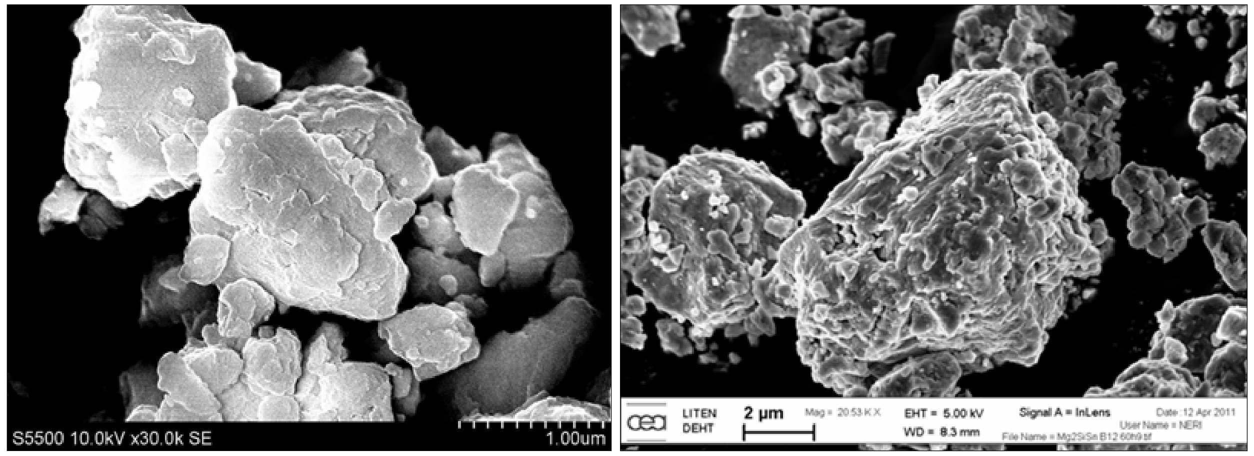

Fig. 8 Mg_2Si (left) and SiGe (right) nano alloy powders used in the EU's NEAT research project [8]

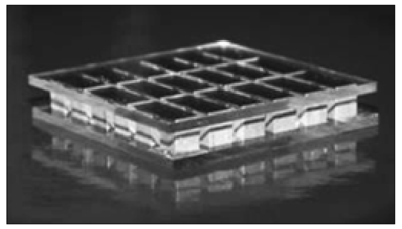

Fig. 9 Thermoelectric generating module developed as part of the EU NEAT project [8]

- Silicide nanoparticles in SiGe alloy matrix (Fig.8 right) for high temperature range (900-1200K)
- A hybrid architecture involving graded composition of both materials, suitable for high thermal gradients.

The correlation between detailed material microstructures and thermoelectric properties has been shown for SiGe and Mg_2SiSn alloys, enabling to demonstrate both the necessity of controlling the process environment and the effect of spontaneous nanostructuration on the materials performances. The performances of the first thermoelectric generators (Fig. 9) assembled in the project showed encouraging results for the final proofs of concepts thermoelectric generators (TEGs) expected in the project.

Nanostructured thermoelectric materials

In Germany the second funding period (2012-2015) of a €17.4 million project on 'Nanostructured Thermoelectric Materials' (DFG Priority Programme SPP1386) involves 33 research partners from Germany plus partners from Switzerland and Austria. The aim will be the development of new thermoelectric alloy systems using nanostructured materials having 200% more efficiency in using waste heat, for example in combustion engines, whilst at the same time lowering CO_2 emissions. The project aims to focus on thermoelectric materials that are environmentally benign, cheap, durable, and efficient. Most of the well-known thermoelectrics are said to fail in at least one respect, so the researchers will explore transition metals containing clathrates and oxides. Different nanostructuring and compaction/sintering techniques for bulk materials will also be explored.

The Fraunhofer Institute for Manufacturing Technology and Advanced Materials (IFAM) in Dresden is coordinating one project within SPP1386 on the nanostructuring of magnesium and manganese silicides which are low cost and low toxicity, and is also involved in a second project on nanostructured Bi-Te materials [9]. The Mg and Mn silicides are reported to have moderate efficiency (~5%) in a temperature range from 350 to 650°C, and this performance can be optpmised by adjusting the properties via doping. Fraunhofer IFAM will use Powder Metallurgy to scale up material manufacture. For the clathrates an innovative synthesis route, from sol gel via calcination to reduction, has been developed and for the bismuth telluride (Bi_2Te_3) nanoparticles a high energy ball milling route is used. In both cases the nano powder is consolidated into a nanostructured bulk material having low heat conductivity using spark plasma sintering (SPS).

Compared to macrocrystalline materials the heat conductivity can be decreased by 20% (clathrates) and 60% for Bi_2Te_3. Fig. 10 shows Mg and Mn silicides of various diameters (1 cm, 2 cm, 4.5 cm and 6 cm) successfully produced by Fraunhofer IFAM via high energy milling and SPS. These are said to be the largest samples produced worldwide at the present time.

Fig. 10 Mg and Mn silicides of various diameters (1 cm, 2 cm, 4.5 cm and 6 cm) produced by high energy milling and spark sintering [9]

References

[1] AIST Today, No.35, 2010.
[2] M. Kambe, T. Jinuchi, Z. Ishijima. *Journal of Electronic Materials* Vol.39, No.9, 2010, 1418-1421.
[3] T. Tsutsui. *Hitachi Chemical Technical Report*, No.54, September 2011, 15-20.
[4] T. Jinushi. Presentation in Seminar on 'Case Studies on Environment and Energy Saving' at PM2012 Powder Metallurgy World Congress, Yokohama, October 2012.
[5] *Science Daily* November 18, 2013.
[6] J. D'Angelo, 'Nanostructured High Temperature Bulk Thermolectric Waste Heat Recovery' (U.S. Dept of Energy Research Program (2011-2015), May 17, 2013. www.gmzenergy.com
[7] K. Biswas, S.Muir, M.A. Subramanian 'Rapid Microwave Sintering of Indium Filled Skutterite – An Energy Efficient Route to High Performance Thermoelectric Materials' Oregon State University, 2011. It.library.oregonstate.edu
[8] www.neat-project.eu
[9] 'Energy from Waste Heat – Thermoelectric Materials for Industrial Applications', published in *Fraunhofer IFAM Annual Report* 2012-2013, pp48-51.

Quality and productivity provide focus for Germany's PM community at the 2013 Hagen Symposium

The Hagen Symposium, organised by the Fachverband Pulvermetallurgie, is the annual meeting for many German-speaking powder metallurgists. The 32nd symposium took place in Hagen's Civic Hall from November 28-29 2013, and Dr Georg Schlieper attended the symposium on behalf of *Powder Metallurgy Review*. His report covers a number of key presentations from the event as well as the awarding of the 2013 Skaupy Prize to Josef Seyrkammer.

Non-destructive testing in Powder Metallurgy manufacturing

The main focus of the 2013 Hagen Symposium was on quality and productivity in Powder Metallurgy. A presentation by Dr Eberhard Ernst, GKN Sinter Metals Engineering GmbH, Germany, provided a comprehensive and systematic review of non-destructive test (NDT) methods used in the quality assurance of PM structural components.

NDT methods are based on physical effects

According to Ernst, all NDT methods are indirect tests based on physical effects which are related to defects in the parts. Mechanical, optical and electrical test methods are available for finding defects (Fig. 1).

All test methods listed in Fig. 1 provide information about certain parts of the test pieces such as the entire volume or local volumes, local surfaces, local surface layers, edges, transitions, notches, etc. They can be applied manually or, preferably, automatically and in line with the production process.

Typical defects in PM parts

Typical defects generated by the PM production process are powder contamination by foreign objects, local density variations, shear cracks and brittle fractures. Foreign objects can have sizes between 1/100 mm and several millimetres, depending on the sieves used prior to filling the powder mix into the die cavity. Either they burn off during sintering and leave hollow spaces or remain as foreign objects, often not firmly connected to the sintered matrix. Small contaminations or pores are non-

Physical effect	Test method
Mechanics	Proof load (non-destructive?)
	Acoustic resonance testing
	Ultrasonic testing
Optics	Visual (camera) inspection
	Thermography
	X-ray, gamma ray (incl. tomography)
Electromagnetism	Eddy current testing
	Barkhausen effect
	Magnetic particle inspection

Fig. 1 Non-destructive testing uses physical effects

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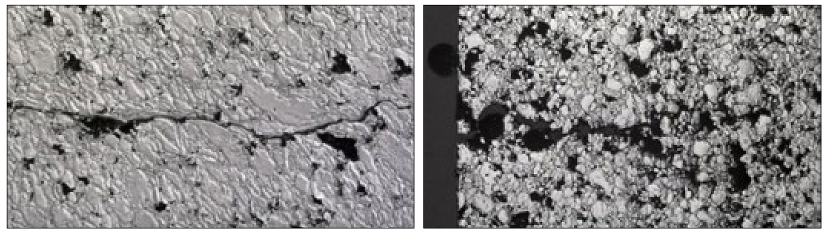

Fig. 2 Shear crack (left) and brittle crack in green PM compacts (Courtesy GKN Sinter Metals Engineering)

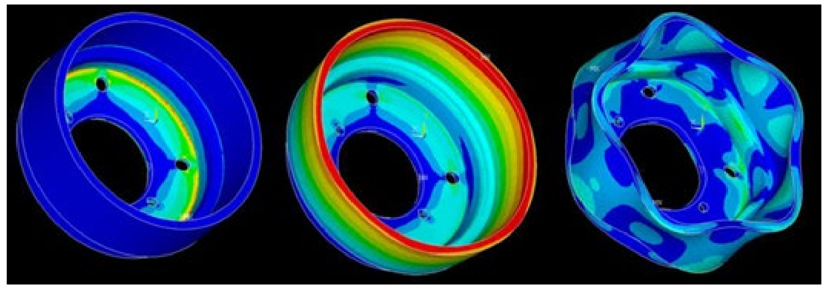

Fig. 3 Possible calculated resonance shapes of a part show the affected areas red-yellow (Courtesy GKN Sinter Metals Engineering)

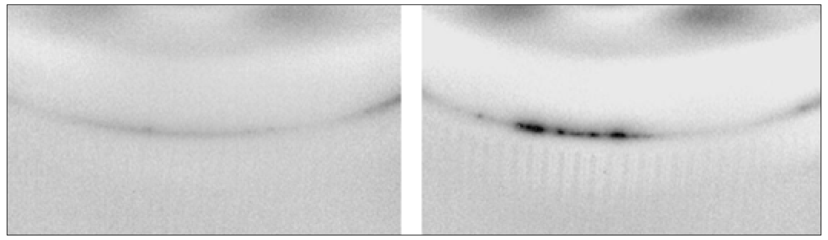

Fig. 4 Infrared image of a PM part with ultrasonic excitation, left without crack, right with crack (Courtesy EDEVIS)

critical since their effect is similar to the pores that the material contains anyway, but larger ones can reduce the strength, particularly for dynamic and alternating loading.

Density variations in PM compacts may occur depending on the tool design and pressing action. They can lead to dimensional problems and should be eliminated prior to volume production. They are then no longer the subject of production-related NDT. Shear cracks are generated during compaction due to powder displacement inside the die cavity. These cracks are so-called "closed" cracks because the material integrity is interrupted without creating an air gap. Brittle fractures that may arise during ejection are usually closed cracks too, but also sometimes open (Fig. 2). Only incorrect handling of green parts usually leads to open cracks.

Ernst concluded that the defects of greatest interest are hollow spaces, possibly with internal foreign objects, and closed cracks. Further, he stated that it is generally necessary to know the nature of possible defects and tune the NDT methods for the defect type and location.

Limits of non-destructive testing

The typical structure of a PM compact consisting of pressed or sintered metal powder particles and pores creates a basic noise signal in practically all NDT systems. A response signal of a defect must be so strong that it can be automatically distinguished from this noise. Consequently the smallest detectable defects must be bigger than the biggest structures of the compact. Ernst estimates the smallest detectable defect size in PM structural parts at 0.5 mm. He evaluated the various NDT test methods regarding their capabilities for powder metal compacts.

Mechanical methods

Applying a proof load whose magnitude is higher than the normal operational loading of the part and smaller than the designed maximum load is very easy to perform, but the risk to damage the part is high. Ernst presented examples where this method had catastrophically failed and did not recommend it.

Acoustic resonance testing is a test that affects the entire volume of a part by exciting resonance frequencies up to 80 kHz. It is fast and therefore suitable for in-line integration. The most relevant resonance frequencies must be recognised and evaluated. It has been observed that even very large cracks were not detected if the correlated resonance frequencies were not considered. Resonance frequencies can shift from lot to lot or even within a lot if the numbers of produced parts are very high. Fig. 3 shows a selection of vibrational modes which can be excited by knocking on a part.

Ultrasonic testing locally introduces a wave signal into the part and the reflected waves coming from all internal surfaces are registered. Ernst stated that defects in the entire volume can be detected with the exception of positions less than 1 mm below the surface and 2 mm below the ultrasonic probe. The orientation of defects must be such that the signal is reflected towards the sensor. If the limitations of ultrasonic testing are considered, it is reportedly a feasible method for inspecting PM compacts.

Optical methods

Visual defects at the surface of a compact, edges, profiles and transitions can be checked with optical cameras. Ernst reported that cracks can only be detected if the gap is at least a few hundredths of a millimetre, limiting optical camera inspection to only special cases.

Attempts at GKN to register variations of heat flow caused by defects with an infrared camera (thermography) were not satisfactory. Artificial defects and brittle fractures in green compacts could not be detected. Ultrasonic excitation of vibrations causing heat dissipation at crack tips of sintered parts required high energies and the ultrasonic frequency had to be suitable to find resonance at the position of the crack (Fig. 4).

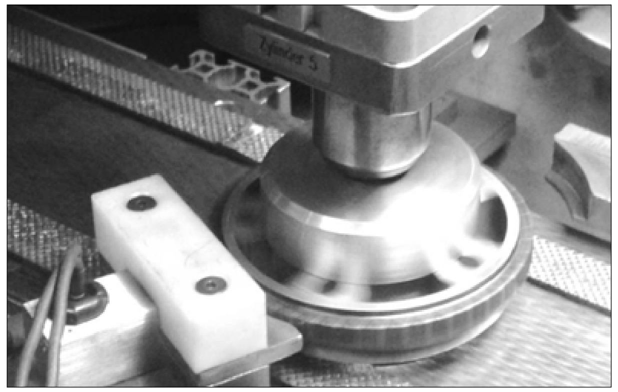

Fig. 5 Barkhausen probe testing a PM gear (Courtesy GKN Sinter Metals Engineering)

According to Ernst, X-ray radiography can only detect defects if the absorption of the radiation is affected by at least 0.5% as compared to the surroundings. Cracks in green PM compacts are usually not volume defects and are therefore invisible for X-rays even if the orientation towards the source is favourable. While digital radiography is fast enough to be used for in-line inspection, computer tomography is so expensive and time consuming that it can only be applied for selected samples.

Electromagnetic effects

A widely used and well-established test method is eddy current testing. It can be applied as an integral test comparing the microstructures of components when parts are passed through a test solenoid or to inspect critical details of a part with specially adapted probes. Typical defects that can be detected are more than 1 mm long and at least 0.5 mm below the surface. Internal cracks at a depth of more than 1 mm cannot be detected.

The Barkhausen Effect, i.e. the discontinuous magnetisation of ferromagnetic materials due to structural details, can be utilised in a similar way to eddy current testing to apply a comparative test of microstructures, but defects are not detected. A gear rotating in front of a magnetic Barkhausen probe is shown in Fig. 5. It is integrated in a production line for 100% inspection of the gear toothing.

Impregnating parts in a magnetic field with a fluorescent liquid containing magnetic particles is known as the Magnaflux test. The magnetic particles are then concentrated at surface cracks which can be detected in UV light. This test has been in use for decades. Attempts were made at GKN for an automatic evaluation of the test in order to eliminate the uncertainties of human inspection. However, the costs were so high that the development was aborted.

In conclusion Ernst stated that non-destructive test methods are not always suitable for finding all possible defects, but they always lead to a better understanding of the manufacturing processes. After all, "quality is not achieved by testing, it is engineered," he stated.

Characterisation of the surface densification process on sintered gear components by numerical methods

Surface densification of sintered gears is an example of the potential that PM technology offers for the development of cost effective components with high strength and precision that can replace wrought gears.

A presentation by Dipl.-Ing. Christian Sandner, Miba Sinter Austria, on 'Characterisation of the surface densification process on sintered components by numerical methods' looked at the application of numerical methods for the development of the gear rolling process.

In Sandner's presentation the reported development was based on Abaqus software which offers a great freedom for individual programming. Due to the specific properties of sintered materials, in particular the lack of constant volume, conventional computer simulation software cannot always be applied.

Definition of a suitable material model and determination of material parameters

Computer simulation of deformation processes for materials with a variable density requires a careful definition of the material model and reliable material parameters. The Gurson-Tvergaard model for material flow considers not only the total porosity, but also the pore shape and interaction between the pores. It requires the determina-

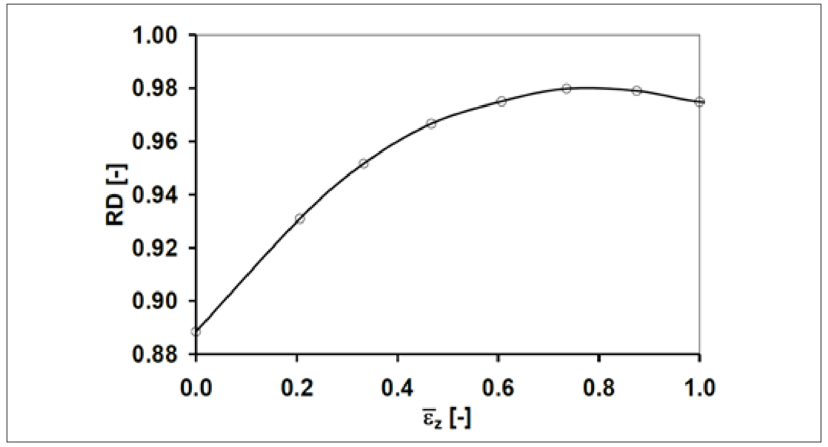

Fig. 6 Relative density (RD) of cylindrical samples as a function of the degree of deformation (Courtesy Miba)

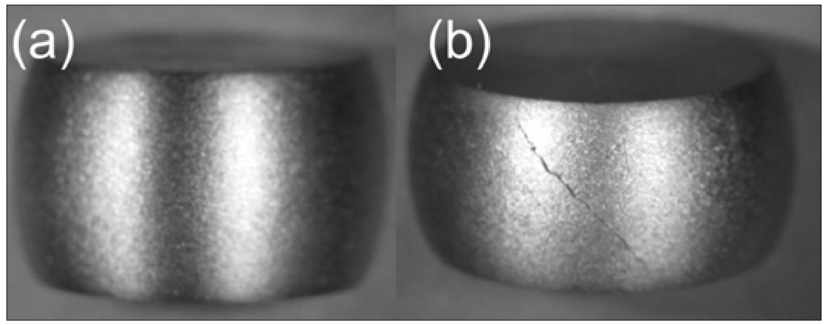

Fig. 7 Cylindrical samples after swaging

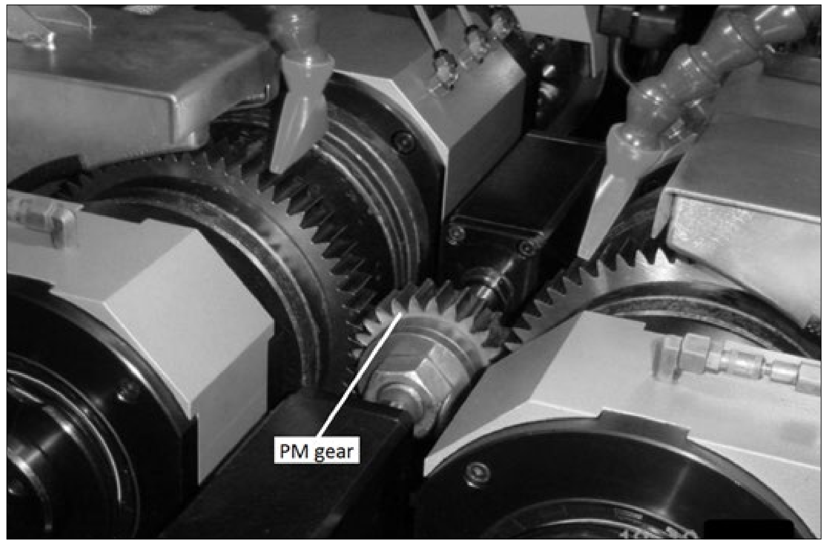

Fig. 8 Gear rolling process (Courtesy Miba)

tion of the following parameters from compressive tests on cylindrical samples.

- Yield stress of the metal matrix as a function of the degree of deformation
- Yield stress of the porous material as a function of the degree of deformation
- Relative density as a function of the degree of deformation

Fully dense cylindrical samples with a diameter of 10 mm and a height of 15 mm made from the gear steel were used to determine the properties of the metal matrix and samples with a relative density of 0.8884 were processed with degrees of deformation between 0.21 and 1. The relative density of porous samples is shown in Fig. 6 as a function of the degree of deformation. Fig. 7 shows the cylindrical samples after swaging. Above a deformation of 0.74 (i.e. 74%) the density fell off again and cracks were observed at the outer surface. Therefore the density at compressive deformations above 70% must be extrapolated.

Surface densification of sintered spur gears

Fig. 8 shows the gear rolling machine with the PM spur gear between two rolling tools. When the PM gear has been positioned and the rolling tools are in the starting position, the rolling process starts by reducing the axial distance at first gradually (centering), then faster (densifying) and finally it is kept constant (sizing).

Sandner reported that this process had been simulated with certain assumptions which were necessary to simplify the calculation. The gear characteristics of a spur gear were: 41 teeth; module 1.75; pressure angle 17°; tooth width 8 mm. The simulated and metallographically determined density distribution is shown in Fig. 9. Metallographic and computed density figures match closely. This is evidence for an appropriate computer simulation.

Practical experience

While spur gears with rolled tooth flanks are state-of-the-art today, helical gears are still under development. For the first time, computer simulation was applied to a helical gear with these characteristics: 44 teeth; module 1.35; pressure angle 15°; helix angle 25°; tooth width 14 mm; high toothing. Since the gear was designed for a grinding finish after case hardening, the densified region had to be well developed in order to provide an allowance for the material removed by grinding.

The gear profiles of the sintered part and the rolling tool were designed as usual based on a cut parallel to the end faces and a satisfactory surface densification by rolling was predicted by computer simulation.

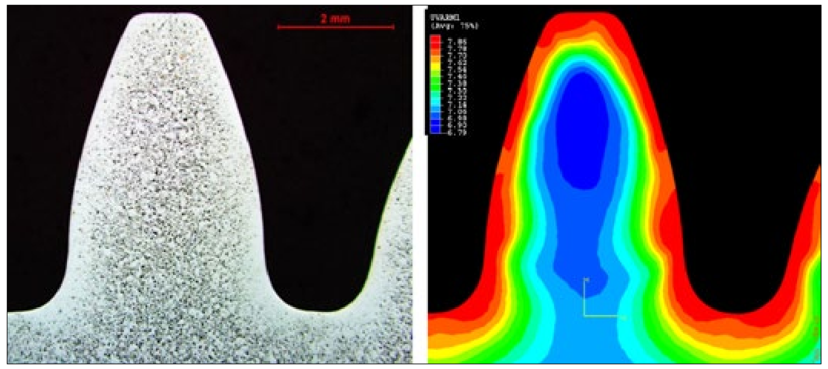

Fig. 9 Metallographic and computed density distribution in a rolled tooth (Courtesy Miba)

Fig. 10 Helical gear rolling tool with fractured tooth (Courtesy Miba)

Rolling tools were manufactured, first samples produced and successfully tested. When volume production started, a tooth of the rolling tool broke after less than 1000 rolled gears (Fig. 10). At first a material defect was assumed, but after repeated tool failures the process was analysed in detail.

Soon it was recognised that the tooth profiles that are relevant for the rolling process are not the ones of the end face cut, but those of the normal cut, i.e. perpendicular to the tooth flank. It is obvious that in this cut the teeth of both the sintered gear and the rolling tool appear significantly thinner than in the end face cut.

A computer simulation based on the normal cut and with consideration of the elasticity of the rolling tools revealed that bending stresses at the rolling tool could increase up to 2000 MPa. By variation of geometrical and process related parameters in the computer simulation it was possible to significantly decrease the maximum bending stresses and thus achieve significantly improved tool lifetimes. To come to the same result by experimental process variation would have been so expensive and time consuming that the PM solution would have been abandoned, added Sandner.

Sandner concluded his presentation with the statement that in modern process development anything that is done in reality should be accompanied by computer simulation. Thereby a better understanding of the processes is acquired and this in turn helps to develop new, improved and stable processes in short times at affordable costs.

Challenges in the manufacture of PM Soft Magnetic Composites

This report is devoted to soft magnetic PM components and summarises the presentation of Dr Andreas Schoppa, PMG Füssen, on PM Soft Magnetic Composites (SMCs).

Schoppa reported that the trend towards electrically powered vehicles creates the requirement for the highly efficient utilisation of energy resources using high performance electric motors and sensors. The optimised application of soft magnetic materials is regarded as a key factor in enhancing the power densities of electric motors.

Although more than 95% of the world market for soft magnetic materials is served by sheet stacks, PM Soft Magnetic Composites have recently started enjoying increased attention from design engineers due to the possibility of producing more complex soft magnetic cores than can be achieved from stacked sheet. While shapes made from sheet are essentially limited to two dimensions and the third dimension is constant, components made from SMC materials can be designed in three dimensions (Fig. 11) and the dimensional accuracy and reproducibility is excellent.

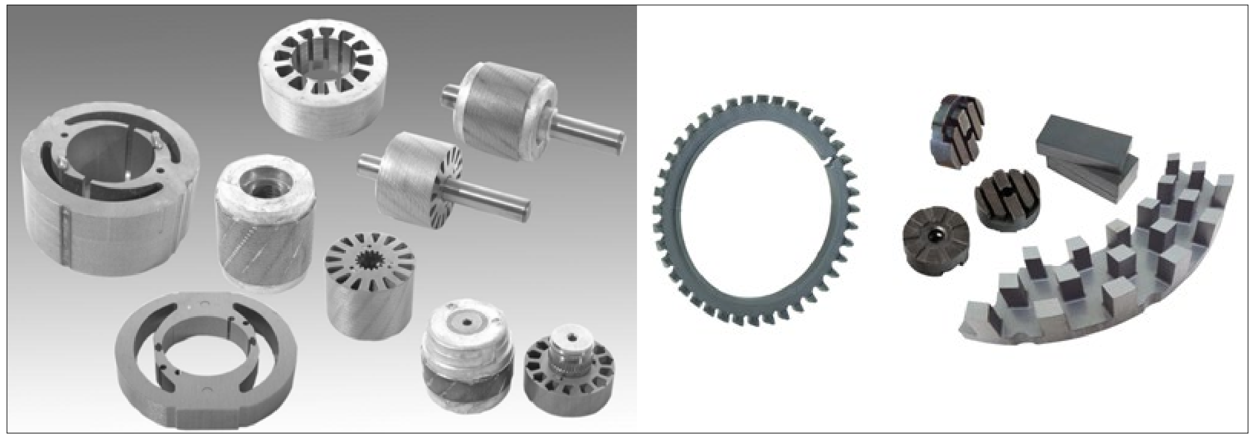

Fig. 11 Soft magnetic cores made from sheet stacks (left) and SMC cores (Courtesy PMG Füssen)

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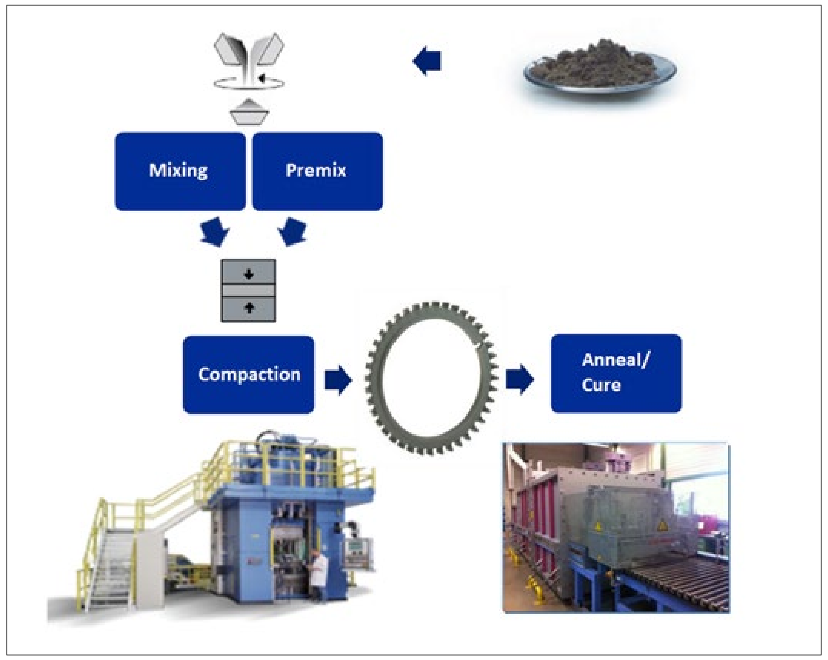

Fig. 12 Processing steps for SMC materials (Courtesy PMG Füssen)

Processing SMC materials

The typical process for SMC components starts by mixing iron powder with a lubricant or binder, followed by compaction and annealing at temperatures between 200 and 700°C (Fig. 12). The annealing process is exclusively intended for curing the binder, not for sintering the iron powder. The powder particles must be electrically isolated from each other in order to achieve the desired material properties.

The process poses a number of challenges for reaching optimum magnetic material properties and consistently high quality. Mixing should ensure a homogeneous distribution of the lubricant or binder. Usually premixes are used that come mixed with the lubricant. Quality control is therefore done by the powder supplier. Care must be taken to avoid the formation of agglomerates during storage.

For optimum magnetic properties the powder is pressed to a density of 7.3 – 7.6 g/cm³ at compacting pressures up to 800 MPa. Additional die lubrication and heating the dies to 140°C can help to enhance the density of the compacts. Die lubricants should be temperature resistant and uniformly applied to the die walls, for example with a spray system. During compaction the lubricant should not penetrate into the base material nor leave detrimental residues after annealing. Some commercial die lubricants leave sulfur and oxygen containing residues that have a negative effect on the magnetic properties.

The annealing process, usually performed in continuous furnaces, determines the strength and final dimensional tolerances as well as the magnetic properties of the finished components. The atmosphere varies; it can be air with or without subsequent steam treatment or nitrogen. Suppliers of premixes usually recommend the annealing parameters. For in-house developments these parameters are usually oriented towards the curing conditions of the binder. For reproducible results it is essential that all furnace parameters, in particular the heating and cooling profiles, are strictly controlled.

Depending on the required volumes and the geometrical complexity of the parts it may be advantageous to save tooling costs by machining the components from blanks or preforms. Certain SMC materials can be machined and the machined surfaces are smooth and uniform. Magnetic properties are hardly affected, so designers do not have to introduce correction factors as they do with machined stacks of sheet.

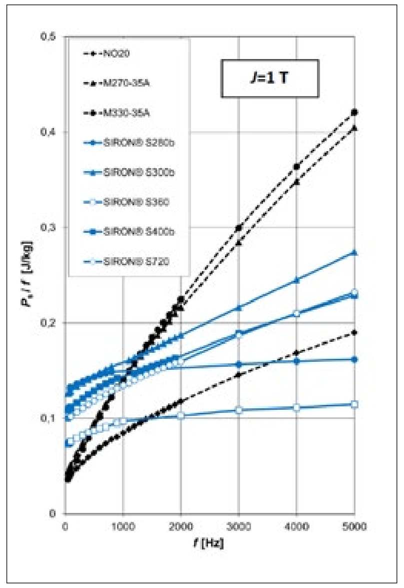

Fig. 13 Total energy losses of sheet stacks (black) and SMC materials (blue) (Courtesy PMG Füssen)

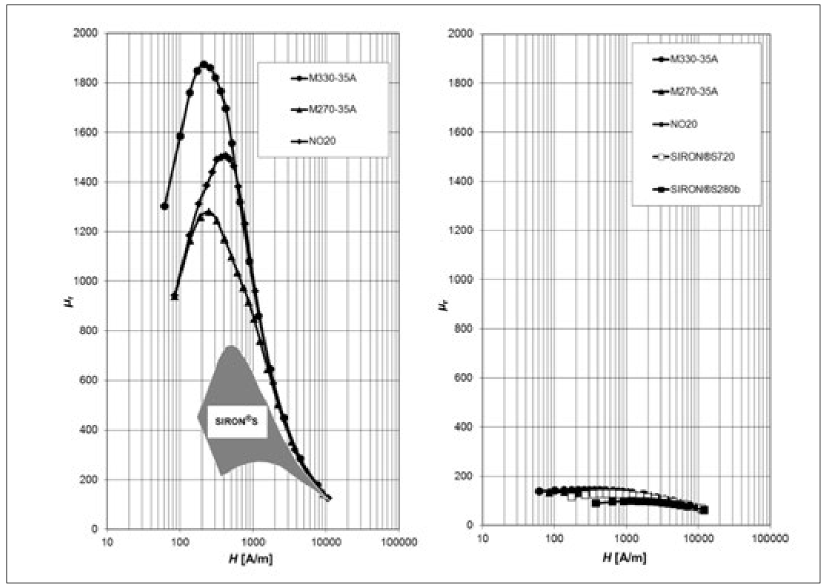

Fig. 14 Relative permeability of SIRONTM SMC materials and sheet stacks at 1000 Hz without air gap (left) and with 0.6% air gap in a magnetic circuit (right) (Courtesy PMG Füssen)

Electromagnetic properties of SMC materials

High speed electric motors operating at up to 20,000 rpm, stated Schoppa, are increasingly used in electro-mobility applications. These high speeds are realised with multi-pole motors that are operated at frequencies between 500 and 5000 Hz. Energy losses inside the ferromagnetic materials are composed of the hysteresis losses, the classical eddy current losses, and anomalous losses depending on the current frequency and grain size of the material.

In lamellar sheet stacks these losses arise in the lamellae and additionally in the individual grains of the microstructure. In SMCs, by contrast, energy losses arise only from the powder particles which are electrically isolated. So, if the total losses are considered as a function of the frequency, PM Soft Magnetic Composites have lower losses at higher frequencies than sheet stacks and enhance the performance and efficiency of the motor (Fig. 13).

According to Schoppa, designers of electric motors often complain that PM SMCs have lower permeabilities than metal sheet. While this is true for magnetic circuits without air gaps at frequencies below 1000 Hz, Schoppa claimed that the difference is hardly noticeable at higher frequencies and in magnetic circuits with an air gap (Fig. 14).

SMC materials are characterised with tests that are common and well established for metal sheet and other soft magnetic materials. Energy losses as a function of the frequency are measured on ring cores of solenoids. It is important to know that the results are affected by the geometry of the test samples and that comparisons between different materials should be made using the same sample geometry. The inductivity of a solenoid with a soft magnetic core measured in an LCR circuit at various frequencies is an easy and feasible method to compare materials and to check the product quality. The static magnetic properties, for example saturation induction and coercive force, are measured in a coercimeter and a low electric conductivity is required for low eddy current losses.

The benchmarks in soft magnetic applications are stacked sheet parts which are produced in high quantities at low cost. Schoppa suggested that the benefits of PM SMCs for electromagnetic applications should be communicated to electrical design engineers and more cost effective PM processes, with excellent reproducibility, should be developed in order to fully exploit the potential of these materials. In his opinion new standards for quality assurance of SMC materials are urgently required.

Current Trends in Quality Assurance

Continuing with the symposium focus of quality and productivity in Powder Metallurgy, Benedikt Sommerhoff of DGQ (The German Association for Quality) gave a presentation on the history of Quality Assurance along with current trends.

The presentation was based on an on-line survey carried out by DGQ in July and August 2013 collecting the opinions of 150 Quality Assurance specialists. Sommerhoff explained that there is a difference between Quality Assurance (QA) and Quality Management (QM). In his presentation he looked exclusively at current trends in Quality Assurance, not Quality Management.

Historic development of Quality Assurance

In Germany, a systematic Quality Assurance was first introduced in volume production processes in the 1950s. This was the industrial sector where initially the greatest benefits were achieved. The early QA units were the precursors of later QM departments. However, Quality Management did not replace Quality Assurance, it was an extension of responsibilities and Quality Assurance, as part of Quality Management, more or less retained its original tasks and methods.

The three main subjects dominating Quality Assurance are:

- Measurement and Testing
- Error Management (error analysis and root cause analysis)
- Requirement Management

Quality Management is additionally concerned with the design of management systems. Another upcoming task for Quality Management is organisational development.

Measurement and testing methods, statistical methods, error and root cause analysis were the main tasks of Quality Assurance from the start. Auditing methods can either be allocated to Measurement and Testing where they are mainly verification of conformity, or to Error Management if the focus is directed at identifying potentials for improvement.

Later, additional responsibilities regarding the legal and contracted customer specific requirements for product and process features were implemented, the so-called Requirement Management. In the 1970s, the QFD method (Quality Function Deployment) was introduced to support this task. Other methods such as FMEA (Failure Mode and Effects

	yes	no
A proper executive department or staff position "Quality Management" is available	98%	2%
A proper executive department or function "Quality Assurance" is available	85%	15%

Fig. 15 Availability of QM and QA (Courtesy DGQ)

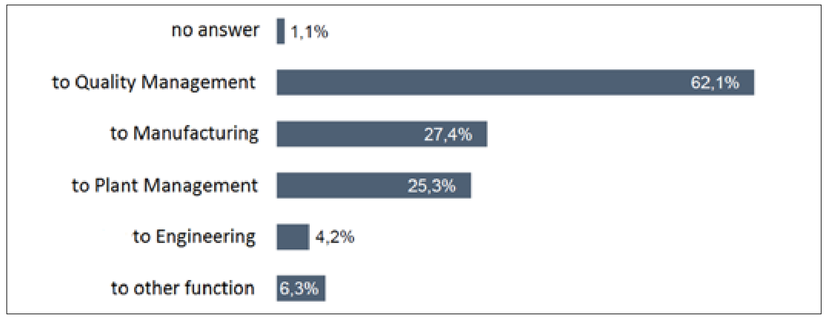

Fig. 16 Affiliation in the organisation of the QA function (Courtesy DGQ)

	yes	no	no answer
A computer based Production Planning and Control (PPC) system is installed	87%	10%	3%
The PPC system is part of a corporation-wide ERP system	69%	17%	14%
The PPC system is part of a Quality Management system	38%	53%	9%
A CAQ system is installed for quality data acquisition	57%	39%	4%
We apply a CAQ system for process control	33%	55%	12%

Fig. 17 Data processing systems in production and QA (Courtesy DGQ)

Analysis) are even older and still in use.

The rapid development of IT technologies has had a fundamental effect on Quality Assurance techniques. In such a data intensive field these innovations could immediately be integrated and in many companies QA specialists were among the pioneers of IT application. Manual data acquisition was soon replaced by QA specific software applications.

The extension of Quality Assurance to Quality Management began with the emergence of TQM (Total Quality Management) in the 1970s and was accelerated by QM System Certifications in the 1980s. Experienced QA specialists were promoted to Quality Managers. The extended tasks and responsibilities of QM often had the consequence that fewer resources were allocated to their original tasks of Quality Assurance so that gradually experience and expertise reduced. The personnel moving up to Quality Assurance were not sufficiently trained in the statistical methods which were increasingly conducted by computers. So a gradual erosion of the use of statistical methods took place which had to be reversed later with great difficulty.

> *"The biggest potential for innovation in Quality Assurance is envisaged in further computerisation and automation of data acquisition and data processing"*

Future trends in Quality Assurance

Future trends in Quality Assurance were identified in a trend scenario QM2020 initiated by DGQ. The most important of these were:

- Growing complexity and variety of products and services
- Extensive automation of data acquisition and error handling
- Expansion of data base and knowledge ("big data")

Trends and changes in Quality Assurance are often associated with changes in the organisation. This is why the survey included questions about the organisational structure of QA and its differentiation from other parts of Quality Management.

When asked about the availability of QM and QA in their organisation, 98% of the participants answered that QM is available and 85% confirmed that QA is available (Fig. 15). This confirmed the high relevance of the survey to the participating quality engineers. The affiliation of the QA department or function within the organisation revealed some of the organisational structure of the industry (Fig. 16). In almost two thirds of the organisations the traditional integration of QA in the QM system is still prevailing; in others QA is affiliated to Manufacturing, Plant Management or Engineering. There was no correlation between the affiliation of QA and the success of QM.

The most widely used basic concepts of Quality Assurance applied by 50-75% of the participants of the survey were worker self-inspection, the zero-defect concept and lean management. Roughly one third applied philosophies such as TQM, Poka-Yoke and Six-Sigma. These methods have been in use for decades and no fundamental change is expected in the near future.

The biggest potential for innovation in Quality Assurance is envisaged in further computerisation and automation of data acquisition and data processing. Therefore the participants were asked about the availability of Production Planning and Control (PPC) systems, Enterprise Resource Planning (ERP) and Computer Aided Quality (CAQ) (Fig. 17).

Automated data acquisition and data networking will help to take even more advantage of quality data for production control and for a robust product development. The differentiation of QM and QA will become wider in the future with the option of a closer and better integration of QA into the manufacturing organisation and engineering.

Modern Quality Assurance in the manufacturing industry will no longer be a subsidiary discipline of Quality Management, but an independent engineering science with close links to QM, Manufacturing and Product Development.

Fig. 18 Josef Seyrkammer (second left) receives his Skaupy Prize. Seen here with Michael Krehl (PMG), Fachverband Chairman, (left) Herbert Danninger (third from left) and Hans Kolaska (right) (Courtesy Fachverband)

Fig. 19 Spikes for snow tires (Courtesy Miba)

Skaupy recipient Josef Seyrkammer recalls Powder Metallurgy milestones during his career at Miba

The Skaupy Prize is the highest honour that the Fachverband Pulvermetallurgie confers to distinguished powder metallurgists. At the 2013 Hagen Symposium Josef Seyrkammer received this recognition for his life-long dedication to the Powder Metallurgy (PM) industry (Fig. 18).

Professor Herbert Danninger, Professor of Chemical Technology, Technical University Vienna, introduced Seyrkammer to delegates at Hagen. Danninger began by stating Seyrkammer was born in Schwanenstadt, Upper Austria, where he passed through lower secondary school and went to an engineering school, obtaining his qualification in higher education (Ma-tura). As a hard-working pupil, his teachers recommended him for a polytechnic of mechanical engineering, but his financial resources were limited so instead he followed his education in mechanical engineering through evening courses.

In 1965 Seyrkammer joined Miba Sintermetall AG in Laakirchen, Austria, where he soon became head of the tool design department and was later promoted to Business Executive. Having worked in the PM industry for the last 48 years, Seyrkammer has experienced the tremendous development of the industry worldwide, actively contributing to it first-hand.

In his Skaupy Lecture Seyrkammer recalled highlights of PM products and processes during his career at the Miba Group.

Early economic boost

Seyrkammer stated that Powder Metallurgy received a first big economic boost with the manufacture of metal spikes for snow tires in the early 1960s (Fig. 19). The spikes sleeves were pressed from iron powder on rotary presses with 41 cavities having a capacity of 24,000 parts per hour. Small conical carbide studs were pressed into the sintered spikes sleeves. For corrosion protection the spikes were electroplated with zinc or painted in different colours. During the peak times, Miba produced 300 million spikes per year. However in 1974 spike tires were banned due to the resulting damage caused to roads.

Growth in automotive applications

Seyrkammer explained that the 1970s and 1980s saw a growing penetration of the automotive market with PM components. The level of PM technology was raised step by step to the quality requirements of the automotive industry and subsequently many new applications were developed.

Fig. 20 First in-line production of timing belt pulleys at Miba (Courtesy Miba)

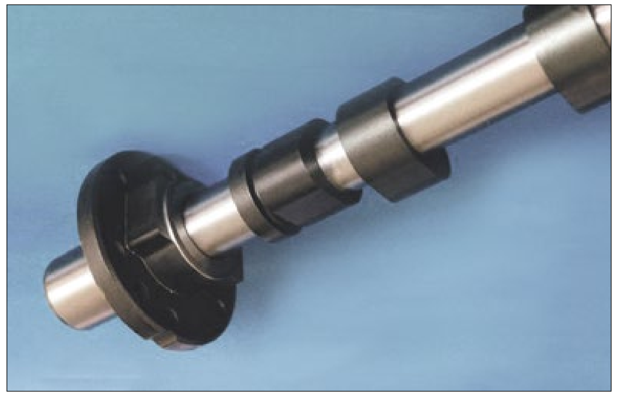

Fig. 21 Assembled camshaft with precision cam lobes for a 12 cylinder fuel engine (Courtesy Miba)

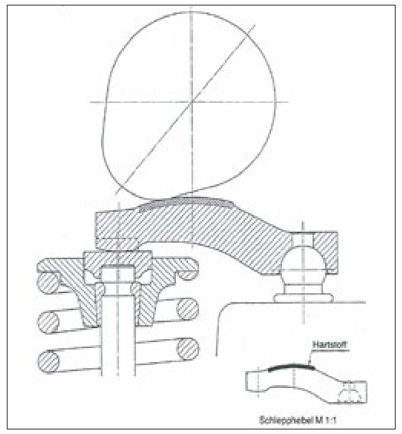

Fig. 22 Functional drawing of the bimetallic towing lever (Courtesy Miba)

Fig. 23 Complete sintered synchronising module (Courtesy Miba)

Investments in research and development, modern tool making equipment, bigger presses were made and know-how for volume manufacturing was acquired. During this period Miba installed the first in-line press-sinter-size production of timing belt pulleys including a 5000 kN hydraulic powder press, a belt sintering furnace and a 6300 kN sizing press (Fig. 20), stated Seyrkammer.

A further important step forward in the late 1980s were the first PM components with high dynamic loading capacity and high density made by Powder Forging (PF), such as truck synchroniser rings. Seyrkammer stated that these comparatively heavy parts were pressed to a green density of 6.9 g/cm³ and sintered at 1200°C. After applying a graphite coating the parts were heated again in a specially developed furnace to 1050°C in endogas and automatically fed to the 10,000 kN forging press.

In the early 1990s the development of sintered cam lobes for assembled camshafts began. The first applications were in engines for low and medium loading with a Hertzian pressure of approximately 600 MPa. The follower components were in most cases barrel tappets with mechanical valve compensation. The cam lobes were made from low alloy steels using the double press and sinter technique. As the load requirements of automotive engines increased to Hertzian pressures of more than 1000 MPa, low alloy steels were no longer sufficient, so cam lobes were made from medium and high alloy steels.

The development work was accompanied by extensive wear testing. The top product of this kind was a precision cam lobe for the assembled camshaft of a 12 cylinder fuel engine (Fig. 21). The follower in this case was a roller towing lever. The outer contour of the cam was concave and in spite of close dimensional tolerance requirements needed no grinding finish, stated Seyrkammer. The cam lobes were double pressed to a density of 7.4 g/cm³ and vacuum sintered at 1200°C.

Bimetallic towing lever

Another highlight of the 1990s was the bimetallic towing lever which combined a sintered steel body with high fatigue strength and a high alloy wear resistant metal surface running against the camshaft (Fig. 22). The tribological properties of the towing lever were excellent and clearly superior to competing technologies like forging and casting, added Seyrkammer. The zone running against the cam was made from molybdenum alloyed steel with a density of 8.3 g/cm³. The parts were pressed in double layer compaction tooling using a specially developed filling system. During sintering at 1300°C an intermetallic phase was developed that was essential for the outstanding wear properties. Finally a surface layer of molybdenum carbide was created in a low pressure carburising process. The area in contact with the valve shaft was induction hardened.

Gearbox applications

A complete synchronising module for the first and second gear of a passenger car manual gearbox consisting of a synchronising hub, two friction rings, synchronising rings, two double cone rings and two fixing rings made from PM steel was developed in the late 1990s (Fig. 23). The parts were assembled and laser welded. Synchronising hub and friction rings were sinter hardened, the synchronising rings were induction hardened in the rooftop areas, the double cone rings were made from hardened steel with subsequent molybdenum coating on both sides. Functional tests of the assembled unit were carried out in-house on a gearbox test bench.

Improvements of existing products and new ones for engine and gearbox applications, power steering, oil pumps and many more followed and were brought to volume production.

In his conclusion, Seyrkammer acknowledged the team of qualified and dedicated staff that has contributed to Miba's growth over the past 50 years. Today Miba is a widely recognised international group of companies with a high technology standard. Constant changes in the automotive industry pose new challenges on Powder Metallurgy that require the full commitment of all PM engineers.

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Dr.-Ing. Georg Schlieper, physicist, received his PhD at the Insitute for Materials and Solid State Research of the University of Karlsruhe, Germany. He worked for 15 years in product and process development for the Powder Metallurgy industry where he focused on high strength sintered steels, heat treatment, surface technology, magnetic materials and metal injection moulding. Since 1994 he has worked independently as a consultant.

PM INDUSTRY EVENTS

2014

10th International Conference on the Science of Hard Materials (ICSHM10)
March 10 - 14
Cancun, Mexico
www.icshm10.org

PM China 2014 - International Power Metallurgy Exhibition & Conference
April 27-29
Shanghai, China
www.cn-pmexpo.com

PM2014 World Congress
May 18–22
Orlando, Florida, USA
www.mpif.org

Additive Manufacturing with Powder Metallurgy
(co-located with PM2014 World Congress)
May 18–20
Orlando, FL, USA
www.mpif.org

HIP 2014, 11th International HIP Conference
June 9 -13
Stockholm, Sweden
www.hip14.se

7th Powder Metallurgy Conference and Exhibition, TPM7
June 24 – 28
Ankara, Turkey
www.turkishpm.org

Sintering 2014
August 24-28
Dresden, Germany
www.sintering2014.com

Euro PM2014
September 21-24,
Salzburg, Austria
www.epma.com

2015

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

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