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POWDER METALLURGY REVIEW

AUTOMOTIVE PM IN NORTH AMERICA

HARDMETAL INNOVATIONS AT PLANSEE 2013

ADVANCES IN PM AT POWDERMET 2013

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POWDER
METALLURGY
REVIEW

Challenges and opportunities as the auto industry adapts to a new global environment

In this latest issue of *Powder Metallurgy Review* we feature a specially commissioned report on the evolving relationship between North America's PM parts producers and the region's automotive industry (page 33), which has dominated the development of the PM industry for many decades. Eric Boreczky charts the rapid growth of the PM industry in the 1990s following the introduction of a number of major new applications, as well as the impact of the recession of 2008. Boreczky also considers the challenges that lie ahead as the globalisation vehicle design leads to smaller more fuel efficient engines.

At the PowderMet 2013 conference held in Chicago in June there was much optimism for PM's future, with new developments in materials, processing technologies and applications being presented for both the automotive and non-automotive sectors. *Powder Metallurgy Review* was present at this important annual event and Dr David Whittaker reports on a Special Interest Program that looked at Technologies for PM Growth (page 57).

There was also much to discuss in the hard materials presentations at the triennial Plansee Seminar which took place in June in Reutte, Austria. Dr Leo Prakash reports for *Powder Metallurgy Review* on presentations covering global R&D trends in hardmetals and the phenomena of cobalt capping (page 41). More in this series of exclusive reports can be found on our website www.ipmd.net.

The growth in the global demand for electric motors also has huge potential for the use of iron-base Soft Magnetic Composites. We report on the development by GKN Sinter Metals, in conjunction with RWTH Aachen, of a new transversal flux motor which uses SMC iron powders in the stators of a new electric motor (page 75).

Paul Whittaker
Editor, *Powder Metallurgy Review*

Cover image
2013 MPIF award winning compressor clutch used in a braking system, manufactured by AMES SA, Spain (Courtesy MPIF)

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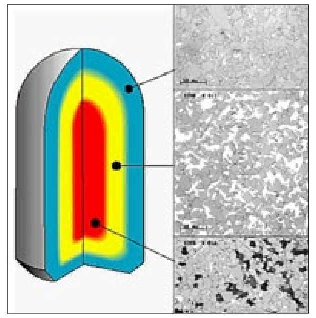
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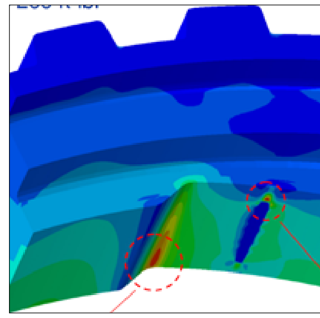
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To submit news for inclusion in *Powder Metallurgy Review* contact Paul Whittaker paul@inovar-communications.com

China's PM industry maintains growth in 2nd quarter 2013

Statistics published by the China Machine Powder Metallurgy Association (CMPMA) show that structural PM part production maintained its growth momentum in the 2nd quarter of 2013 with output increasing to 45,124 tonnes, which is a 12.6% increase compared with the previous (1st) quarter of 2013.

This takes total PM production for the first half year to 85,165 tonnes, an increase of 8.7% compared with the same period in 2012.

In terms of sales value the CMPMA reported an increase of 7.3% for the first half year at Yuan 2,860 million ($467 million). The figures are based on the responses from 47 PM enterprises to the CMPMA

GKN continues to make good progress in 2013

Group results issued by GKN plc for the first six months trading in 2013 showed that sales increased by 12% to £3,647 million (up 2% on organic basis) compared with the same period in 2012. Reported profit before tax of £134 million (2012: £279 million) was lower, primarily due to foreign exchange rate changes.

"GKN has continued to make good progress against our strategy to grow a market-leading global engineering business. Although some of our end markets remained challenging, we continued to outperform and are reporting good underlying financial results with further benefit from last year's acquisition, GKN Aerospace Engine Systems (formerly Volvo Aero), which is performing well. The first half met our expectations and, with planned restructuring costs now behind us, we expect a stronger second half performance and to deliver good progress in 2013," stated Nigel Stein, Chief Executive of GKN.

The GKN Powder Metallurgy Division sales grew by 2% to £480 million in the six month period with a trading margin of 10%. The PM Division is expected to show good year-on-year sales improvement, although reflecting normal seasonality.

www.gkn.com

Rio Tinto plans new metal powder annealing plant in India

According to a report published on India's dna website, Rio Tinto has announced plans to set up a new metal powder annealing plant at Bharuch, India.

A Rio Tinto official told the daily broadsheet "The project covers an option to build a metal powder annealing plant. A modest investment and the time frame is still uncertain."

"Global demand for metal powders is driven mainly by the automotive sector, where manufacturers are increasing their intensity of use to lower automobile weight and increase fuel efficiency. Metal powders are also used in the fabrication of home appliance and power tool components, and as food supplements," the company added.

The report stated that it is likely that the proposed plant in Bharuch would be supplied with raw atomised powder from Rio Tinto's metal powder plant in Tracy, Canada.

www.riotinto.com

Höganäs reports increase in sales volumes in second quarter 2013

Höganäs AB has reported sales volumes in the second quarter 2013 were up 2% compared to the corresponding period of the previous year. However, the Swedish metal powder producer recorded a 9% drop in net sales year on year, with net sales of MSEK 1,652 for the period, compared with MSEK 1,808 in Q2 2012.

As an effect of falling metal prices, metal price surcharges on all significant metals were lower than in the second quarter 2012 added Höganäs. The Swedish krona remained volatile in the quarter and overall the currency effect on sales values was 7% negative compared to the previous year.

"Global market progress presents a divided picture. We are satisfied to see the progress of our volumes in North America and China, while demand conditions were sluggish on some other emerging markets in the spring. In Europe, we saw a marginal sales increase, thanks to Eastern Europe," stated Alrik Danielson, Chief Executive Officer. "Thus, Höganäs' broad geographical diversity meant that sales volumes for the first half-year were fairly good overall. However, to reduce the risk of holding excessive inventories in the autumn, we decided to run lower production volumes than the previous year in the spring, as reflected in our improved cash flow."

First half 2013

The company reported first half 2013 net sales of MSEK 3,229, down 11% year on year. Sales volumes were also down 0.3% in the period.

Höganäs stated that sales volumes in Europe were down on the corresponding period of 2012. Although the downturn is only marginal, the company states that austerity measures in Europe appear to be holding the region's recovery in check in several market segments. Sales performance in Asia was pushed in a positive direction by China, while strong comparative figures for 2012, due to the recovery post-tsunami and flooding, meant most other countries reported sales downturns.

Healthy growth was achieved in North America as continued positive car production forecasts and market sentiment improved in many other segments. In South America high inventories at the customer level caused fairly weak sales early in the period, stated Höganäs. The growth stimulus measures the Brazilian government has taken in the past two years did generate a gradual positive effect, and volume performance progress in the second quarter was gradually more positive.

www.hoganas.com

Plansee Group announces second most successful year ever

With the divisions Plansee High Performance Materials, Global Tungsten & Powders (GTP), Ceratizit (hardmetal tools and wear parts), and the investment in Molymet, Austria's Plansee Group is today one of the leading global Powder Metallurgy companies covering the whole supply chain of the high-tech materials based on molybdenum and tungsten, from ore processing to the production of customer-specific components.

In the recently announced results for the last fiscal year 2012/13, which ended on the last day of February 2013, the Plansee Group generated consolidated sales of €1.23 billion and employed a total of 5,710 people worldwide. Group sales were down 19% on the previous fiscal year with the main reason being the sale of the PMG division (structural PM parts) at the end of 2011. PMG had contributed annual sales of €200 million. The sales figures also reflect the customers' cautious purchasing strategies and a fall in the prices of raw materials.

Dr. Michael Schwarzkopf, Chairman of the Executive Board of the Plansee Group said in presenting the results that, "bearing in mind that we have had to operate in a global market environment characterised by uncertainty and that previously booming China provided only little stimulus, we are extremely satisfied. In financial terms, 2012/13 even turned out to be our second most successful year ever." As in the preceding year, sales outside of Europe accounted for 52% of the Plansee Group total (America 31%, Asia 21%, Europe 48%). Half of Group sales were achieved in three sectors: mechanical engineering, automotive and consumer electronics.

During the last fiscal year, the Plansee Group made investments of more than €180 million. This included additional production capacity in Austria, Germany, the USA, China and India as well as the holdings in Molymet and recently acquired Günther Wirth. The new Plansee High Performance Materials production plant in Shanghai is due to start production in this summer. Plansee spent €29 million on product and process innovations.

www.plansee.com

New President and CEO at PMG Indiana Corporation

PMG Holding GmbH, headquartered in Füssen, Germany, has announced that Josep Planas has been appointed President and CEO of PMG Indiana Corporation. It was stated that Ron Krause, the former President of PMG Indiana Corp., will resume new responsibilities within the PMG group.

Planas has held various positions in the Powder Metallurgy industry and within the PMG group. He has worked as head of manufacturing and COO at PMG Polmetasa S.A.U. as well as being responsible for several successful technology transfer projects and a number of complex new launches of production lines within the PMG group.

In the US, PMG is currently investing around $23 million to build a second manufacturing facility on its 40 acre campus in Columbus, Indiana. Planas' wide experience within the PMG group will help him to realise the planned expansion project successfully, the company stated.

www.pmgsinter.com

Kennametal sees drop in sales, but upbeat for coming financial year

Kennametal, one of the world's leading cemented carbide and hard material producers reported that final quarter sales (April to June 2013) were down 9% to $671 million compared with the same quarter last year. This reflected an 8% organic decline and a 1% unfavourable effect from currency exchange. Operating income was $91 million, compared with $117 million in the same quarter last year.

"In the June quarter, and for every quarter during fiscal 2013, Kennametal delivered double-digit profitability despite market challenges. We demonstrated greater agility in this cycle and elevated our financial performance," stated Carlos Cardoso, Kennametal Chairman, President and Chief Executive Officer.

For the full financial year ending June 2013 Kennametal reported sales of $2.6 billion, compared with $2.7 billion last year. Operating income for the financial year was $296 million, compared with $416 million in fiscal 2012.

For the fiscal year 2014, Kennametal's outlook reflects expectations of continued macro-economic improvement, with worldwide industrial production building momentum. The company expects organic sales growth to range from 5 to 7%, and total sales to grow between 4 and 6% in fiscal 2014. This growth rate is expected to outpace global industrial production by more than double through company-specific initiatives.

www.kennametal.com

Lower sales at Sandvik AB in first half results

Sweden's Sandvik AB has reported that total invoiced group sales for the second quarter (to end of June 2013) amounted to SEK 23,043 million, down 6% on the same period in 2012. Invoiced sales for the first half of 2013 amounted to SEK 45,142 million, down 5%. Operating profit for the first half was reported as SEK 5,518 million (SEK 8,031 million in same period in 2012), with a margin of 12.2% of invoiced sales.

Market activity for Sandvik Machining Solutions, the largest segment in the group, which includes production of cemented carbide cutting tools, remained largely on a par with the first quarter. This segment contributed SEK 14,258 million in sales, down 3%, in the January to June period, whilst Sandvik Materials Technology reported invoiced sales of SEK 7,451 million.

Sandvik Venture, which includes superhard and hard materials based on cemented carbides, cubic boron nitride, and synthetic diamond, as well as tungsten and tungsten carbide powder producer Wolfram, reported invoiced sales of SEK 2,603 million for the first half 2013.

It was decided in the second quarter to form a new product area within the Sandvik Venture segment combining Diamond Innovations and Sandvik Hard Materials. The new product area will have approximately 1,800 employees and will bring together resources within R&D, sales and marketing for superhard and hard materials, stated the company.

www.sandvik.com

Growth of Metaldyne business recognised in regional awards

Metaldyne LLC has announced that it was named one of the fastest growing businesses in the Detroit metropolitan area by Crain's Detroit Business for the second year in a row.

The list ranks private and public companies headquartered in the Detroit metropolitan area, USA, by two factors, dollar revenue growth and percentage revenue growth over the past three years.

Metaldyne exhibited revenue growth of 59% between 2009 and 2012, from $630 million to over $1 billion. "By focusing our investments in our engine, transmission and driveline product and process technology, Metaldyne has seen substantial growth," stated Thomas Amato, Metaldyne's President and CEO. "We are honoured to once again be included in this group of excellent companies headquartered in the metro Detroit area."

The company's biggest area of growth came from its powertrain segment, where Metaldyne introduced new technologies "to improve or support the performance of advanced and more fuel-efficient engines and transmissions," stated Amato.

Other notable supplier recipients included Borg Warner Inc., American Axle & Manufacturing Holdings Inc., TI Automotive, Piston Automotive, Lear Corp., TRW, Meritor Inc., in addition to automotive OEMs Chrysler Group LLC and General Motors.

"We appreciate the acknowledgement, which is a testament to our culture of continuous improvement and commitment to operational excellence throughout all of our locations. All Metaldyne employees work hard every day, and this is a result of their efforts," added Amato.

www.metaldyne.com

Miba Sinter investing $7 million in US expansion

Austria's Miba Sinter Group is investing $7 million in the expansion of its plant in McConnelsville, Ohio, USA, according to a report in the Morgan County Herald.

"We will be doubling the size of our plant by February 2014 because our existing plant is full now. We have more equipment arriving in February, so the plant addition will be completed by spring. We will also be hiring another 30 people within the next six months, and we will create about 100 jobs within three years," stated Steve Krise, Site Manager of Miba Sinter Group in McConnelsville.

Miba's plant primarily supplies the North American auto industry, producing parts for manufacturers such as Ford, General Motors, Chrysler and Volkswagen.

GKN plans new regional headquarters for the Americas

An artist's impression of GKN's new 168,000 ft² facility

GKN Driveline and GKN Sinter Metals are expanding their automotive operations and moving to a new regional headquarters for the Americas in the Detroit suburb of Auburn Hills early next year.

The new site will also house employees from GKN's Land Systems and North American Services groups. Construction of the 168,000 ft² facility is scheduled to begin in August on an 11.2 acre site.

Headquartered in Auburn Hills since 1986, GKN has more than 300 employees at its current 113,000 ft² facility. Employment is expected to grow by 50 or more full-time employees in the next three years.

GKN Driveline is the world's leading producer of automotive driveline components and systems including constant velocity joint, all wheel drive, trans axle and electric drive systems. GKN Sinter Metals is the world's largest producer of precision powder metal products.

GKN's new headquarters complex will provide additional space for state of the art testing and validation equipment along with additional engineering design areas for driveline and sinter metal products. Executive management teams from both GKN Driveline and GKN Sinter Metals will be located in the new headquarters building along with various engineering groups and other corporate activities.

Robert Willig, President of GKN Driveline Americas, noted that the need for additional space and resources has become paramount in view of GKN's substantial growth in recent years and the number of major new program launches planned for the Americas.

"GKN has significantly increased its engineering resources in the past four years and plans to recruit and hire even more engineering personnel to support more than 100 new program launches in the next three years for GKN Driveline and GKN Sinter Metals," stated Willig. "Our new headquarters facility underlines our commitment to our customers and to the Americas."

Chris Franks, President, GKN Sinter Metals Americas, added, "The additional space is ideally located in close proximity to many of our global customers and will give us access to the additional resources needed to provide our customers with world-class precision powder-metal products and allow us to deliver on our corporate vision of providing engineering that moves the world."

GKN officials also acknowledged the tremendous support provided for the project by Michigan Governor Rick Snyder's office, the Michigan Economic Development Corporation and the City of Auburn Hills.

www.gkn.com

Miba reports Q1 results and looks to USA and China for growth

Miba AG, one of Austria's leading industry and technology corporations, has reported that despite the highly challenging market environment the group held its ground in the first quarter of 2013–2014. Consolidated sales in the first quarter (February 1 to April 30) equalled EUR 153.5 million, a decline of some EUR 7.4 million or 4.6% when compared to the first quarter of 2012–2013. EBIT was reported at EUR 17.8 million, a drop of EUR 2.4 million when compared to the previous year's figure.

Despite the cautiously optimistic outlook of the International Monetary Fund which anticipates global economic growth of 3.3% in 2013, the development in Miba's sales markets is difficult to predict in the medium term, the report stated.

Miba stated that it is not relying on further growth for the 2013–2014 business year as a whole, but is expecting noticeable recovery in the longer term particularly in the USA and China, where the company plans to invest more than EUR 30 million in additional production capacities at its China site over the next few years. In the USA, the Company is preparing for another major order from the North American construction equipment industry.

Investments are also planned for the sites in Austria, with a new input stock production line for bearings in Aurachkirchen.

F Peter Mitterbauer takes charge and outlines future goals

Miba AG confirmed that F Peter Mitterbauer began his new role as Chairman of the Management Board on July 1, 2013. The move, announced earlier this year, sees F Peter Mitterbauer succeed his father Peter Mitterbauer as head of the Austrian technology group.

As new Chairman of the Management Board F Peter Mitterbauer is now responsible for the New Technologies Group, Strategy, Human Capital, Controlling, Innovation & Technology and Communications. "My goal is to further strengthen the position of the Miba Group as a technology group," stated F Peter Mitterbauer.

The new CEO of the Miba Group feels that even though the company has consistently widened its range of products in the past years, it is still too often viewed as a classic automotive industry supplier. "At 40%, the passenger vehicle sector is still the main contributor to total sales and remains the company's mainstay, however, other business areas such as construction equipment, energy (power plants, power transmission) and the production of special machinery are becoming more and more important."

Mitterbauer claims that internationalisation, innovation and technology are at the top of his priority list. "We develop - also in close cooperation

PM gears manufactured by Miba Sinter Group

with our customers - products and solutions for tomorrow and beyond. To push forward our goal of profitable growth, we need to be close to our customers and act internationally. That is why I want to win, develop and keep the best employees for Miba." Mitterbauer is convinced that this strategy will make it possible to achieve the Group's 2015 goal of EUR 750 million in sales.

As of July 1, 2013, the Miba AG Management Board will have a total of four members. In addition to F Peter Mitterbauer, Wolfgang Litzlbauer is now Vice Chairman of the Management Board, responsible for the Miba Bearing Group, the Miba Friction Group, the Miba Coating Group and Purchasing, while Harald Neubert heads up the Miba Sinter Group and is also responsible for central quality assurance. The latest member is Markus Hofer, who as Chief Financial Officer is responsible for Corporate Finance, IT and Business Excellence.

www.miba.com

GT Advanced Technologies acquires Thermal Technology LLC

GT Advanced Technologies, headquartered in Nashua, New Hampshire, USA, has announced that it has acquired California based Thermal Technology LLC.

This spark plasma sintering furnace was manufactured by Thermal Technology

Founded some 60 years ago, Thermal Technology develops and sells a wide range of high temperature thermal and vacuum products used in the fabrication of advanced materials.

GT has acquired several key products and technologies that will allow it to address new markets with a range of production equipment options. This includes annealing technology that the company believes will be important in the manufacturing of sapphire cover screens; crystal growth technology based on the Kyropoulous growth method and edge defined film growth (EFG) technology for large surface area sapphire. The company has also acquired Spark Plasma Sintering (SPS) technology, which allows dense ceramics to be obtained under uniform heating at relatively low temperatures and in short processing times. The SPS technology is expected to have a wide range of applications including with medical applications, sputtering targets, space applications and thermoelectric convertors for hybrid electric cars.

"The acquisition of the Thermal Technology business adds a number of innovative and important products and technologies to our rapidly diversifying portfolio that will, we believe, allow us to accelerate our entrance into new markets," stated Tom Gutierrez, GT's president and CEO. "The acquisition expands our served markets and complements several of our current product lines. "

"This is an exciting moment for the company, our employees and our customers," stated Matt Mede, President and CEO of Thermal Technology. "The acquisition will open new opportunities for growth for our products and technology as we integrate them into GT's business operations. Leveraging GT's leadership in engineering and product development and their strengths in low-cost global supply chain management will accelerate the time-to-market of our technology to drive market adoption in several promising markets as we go forward. Customers will also benefit through GT's global service and support capabilities."

www.gtat.com
www.thermaltechnology.com

Japan's leading PM companies helped by devaluation of Yen

The 20% devaluation of the Japanese Yen against the US Dollar since the end of 2012 has resulted in a much improved business environment for many Japanese companies, including those in the PM industry.

Mitsubishi Materials Corp. (MMC) reported an increase of 16% in consolidated group net sales for the first quarter of its new financial year (2013/2014) ended June 30 to Yen 423 billion ($4.4 billion). This is largely due to the 13.5% rise in cement sales and a 13.8% rise in sales of the metals division. MMCs 'Advanced Materials & Tools' division, which includes Diamet Corp, Mitsubishi Materials Tools Co., Ltd. and MMC Superalloy Corp, continued in negative territory in the quarter with a 1.7% decrease in sales to Yen 36 billion ($369 million). However, operating profit for the Advanced Materials & Tools division increased by 15.1%. There were reported increases in sales for cemented carbide tools as a direct result of the depreciation of the Yen, but sales of PM parts decreased due to the end of eco-car government subsidies in Japan.

Sumitomo Electric Industries (SEI) also reported buoyant first quarter sales to June 30 with an 11.4% increase to Yen 587.4 billion ($6.02 billion). Group net income improved by 13.8% to Yen 15.9 billion ($163 million). The 'Industrial Materials & Others' division at SEI, which includes the production of cemented carbides (hardmetals), PM parts, and the fully owned A.L.M.T. subsidiary which produces W, Mo, heavy metal, thermal management materials, ceramics, diamond tools and hardmetals, reported a 4.4% increase in division sales to Yen 72.2 billion ($740 million). Sales of structural PM parts increased by 3.3% in the quarter to Yen 12.2 billion ($125 million), whilst hardmetal (cemented carbide) sales increased by 7.1% to Yen 19.5 billion ($199.8 million), and sales at A.L.M.T. increased by 10.3% to Yen 9.6 billion ($98.4 million).

SEI launched its new mid-term management plan in April 2013 called VISION 2017 which aims to match last year's record earnings or to reach even higher levels through prior investments in capital assets and research and development in the sectors covered by its divisions. VISION 2017 targets consolidated sales of Yen 3 trillion, operating income of Yen 180 billion and ROA of 9% by the financial year ending March 2018.

The 'Industrial Materials & Others' division is reported to have spent Yen 6.8 billion ($70 million) in R&D over the past year. The division plans to increase sales of cutting tools to newly emerging markets such as Brazil, Indonesia and Turkey. SEI recently started full-scale production at its new hardmetal factory in Hokkaido where Hokkaido Sumiden Precision Co Ltd has introduced super high-efficiency production lines to meet global demand for hardmetal tools. These production lines have doubled output per employee and increased productivity per unit of space by 30%. Production lead times for cemented carbide indexable inserts have been halved from previous levels to 6 days.

In the sintered parts sector SEI has established a manufacturing and marketing joint venture with WLK Group and Santini Group, both industry leaders in Indonesia. SEI states that it is committed to developing new PM products using soft magnetic iron powders which have excellent magnetic properties in the high frequency range, as well as high performance soft magnetic powder materials to support EV and HEV applications.

A.L.M.T. is also accelerating new product development and marketing in the electronics field, including precision diamond tools for semiconductor nano- and micro-processing. The company has developed a high-hardness nano-polycrystalline diamond made from ultra-fine grains of several tens of nanometers using a new ultra-high voltage technology and a proprietary new manufacturing process. The SEI Group is also developing technology for recycling of tungsten and cobalt powders.

Hitachi Chemicals Ltd reported that sales in its 'Functional Materials' and 'Advanced Components & Systems' divisions increased by just 1% to Yen 119 billion ($1.2 billion) for the quarter ending June 30, 2013. Sales in the Advanced Components & Systems division, which includes structural PM parts and PM bearings, decreased by 2.2% to Yen 53.7 billion ($550 million) compared with the same quarter in 2012. The decrease was attributed to a decline in sales of industrial batteries and systems. However, operating income for the two divisions at Hitachi Chemicals increased by 10.6% to Yen 7.5 billion ($76.9 million) in the quarter.

Schunk Group celebrates its 100th Jubilee

The Schunk Group, with its headquarters in Heuchelheim, Germany, celebrated its 100th Jubilee in August with its approximately 8,300 employees at more than 60 locations worldwide joining in the celebrations.

The company was founded by Ludwig Schunk and Karl Ebe as Schunk & Ebe in Fulda in 1913 for the production of carbon brushes for dynamos and engines. After Karl Ebe passed away, Ludwig Schunk led the company successfully until his death in 1947. In his will Ludwig Schunk stipulated that the company be preserved as a Foundation for the employees, and the Ludwig-Schunk-Stiftung e.V. Foundation was established.

"Ludwig Schunk's will still shapes our corporate culture," stated CEO Gerhard Federer. "It obliges us to continually develop and maintain the company's independence. Our business strategy geared towards long-term growth makes Schunk a secure and attractive employer throughout the world. This is also evident in the extraordinarily strong loyalty our employees have to the company."

Schunk sees its large investments in its facilities, which the company makes all over the world, as also being an investment in and for the employees. "With a great deal of commitment and creativity, our employees have continually developed Schunk into what it is today, a successful globally operating technology corporation. The many exciting jubilee events being held this year at all our facilities are first and foremost a way of thanking all our staff," says Federer.

In the hundred years since its establishment, Schunk & Ebe has become a globally operating corporate group with four divisions; Schunk Materials, Schunk Sinter Metals, Weiss Group (environmental simulation and climate technology) and Schunk Sonosystems (ultrasonic joining technology). The original product range covering carbon brushes are today produced in the Group's Materials Division along with technical ceramics, pantograph contact strips, etc.

The Powder Metallurgy products are produced at three main plants in the Schunk Sinter Metals Division, two of which are located in Thale and Giessen, Germany and another in Mexico. Thale specialises in larger PM parts produced on powder presses ranging from 150 to 1500 metric tonnes force and also Metal Injection Moulded parts, whilst the PM plant in Giessen produces smaller PM parts, PM bearings and sintered filters with powder press capacity up to 150 tons. The Schunk Sinter Metals Division contributed around €140 million to Group sales of €930 million in 2012.

The Schunk Group recently reported that Gerhard Federer, CEO of the Schunk Group, will retire from his position with effect from October 31, 2013 due to health reasons. He will be succeeded on November 1, 2013 by Dr Arno Roth, a long-time member of the Management Board who is currently responsible for the Weiss Group and Sonosystems divisions.

www.schunk-group.com

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Dion Vaughan appointed Chief Executive of specialist metal powder producer Metalysis

Metalysis, the UK based specialist metals producer, has announced the appointment of Dr Dion Vaughan as Chief Executive. He succeeds Guppy Dhariwal who is retiring, having joined the firm in 2010. Dion is a trained metallurgist and has worked across the metals, mining and investment sectors including Hatch Corporate Finance, Sheffield Forge Masters and JP Morgan.

Metalysis has developed an entirely new way of producing high value metal powders that reduces the cost and environmental impact of metal production as compared with existing processes. The Metalysis technology is able to transform metal oxides, such as ores directly into metal powders in a single step. It is currently focusing on the high value specialist metals titanium and tantalum.

As a result Metalysis believes that it can play a critical role in two manufacturing revolutions over the coming years. The powders produced by the Metalysis process, states the company, will dramatically change the production of high value titanium components both utilising existing manufacturing techniques and driving forward the adoption of 3D print in specialist metal products.

In addition, this new technology has the potential to significantly reduce the cost of specialty metal powder production. This means previously expensive metals such as titanium can be used in a variety of new applications to satisfy the latent demand for a low cost, light weight, high strength and corrosion resistant metal.

The nature of the Metalysis process means that it can produce alloys that would not be cost effective by traditional processes. It is entirely solid-state; therefore metals with significantly different densities or melting points can be alloyed. These innovative alloys can be tailored to have the desired properties for applications within a variety of industries including automotive, marine, electronics, clean energy and aerospace.

Tony Pedder, Chairman of Metalysis commented, "The company has performed well on its science and technology goals, which has enabled the Board and shareholders to develop a new scale-up plan for the business. This plan, based on simpler and cheaper production cells, is a longer term plan and so it is a natural time for Guppy, who has done a very good job in re-organising the company, to hand over to Dion Vaughan to deliver an exciting future for Metalysis."

Dr Vaughan added, "Our future emphasis will be on further developing our strength in science and technology, where the company has historically performed, and on partnering with leading metals companies who can help with engineering scale-up and market adoption. The company is already making good progress in exploring such partnering arrangements".

www.metalysis.com

Changes in SMS Meer's supervisory and managing boards

SMS Meer has announced that with effect from July 1, 2013, Heinrich Weiss, who has been responsible for the development and leadership of the group of companies for the last 45 years, will be resigning from his post on the Managing Board and will assume the Chairmanship of the Supervisory Board. The present Chairman, Dr Manfred Bischoff, will become a Member of the Supervisory Board.

Dr Joachim Schönbeck, who is already a Member of the Managing Board, will be appointed to represent the Company externally with effect from July 1, 2013. Jointly with his colleagues, Burkhard Dahmen and Eckhard Schulte, he will continue to constitute the Management of SMS GmbH.

Dr Joachim Schönbeck will be primarily responsible for SMS Meer as before, Burkhard Dahmen will be responsible for SMS Siemag (including the Paul Wurth majority holding) and Eckhard Schulte will be the CFO of the group.

www.sms-meer.com

Carpenter names new leader of Performance Engineered Products division

Carpenter Technology Corporation has named Gary Heasley as the company's new Senior Vice President - Performance Engineered Products (PEP). As of Monday July 22, Heasley will have responsibility for Carpenter subsidiaries Amega West Services, LLC, Dynamet, Inc., and Carpenter Powder Products, Inc. He will also oversee Carpenter's distribution businesses, Latrobe Specialty Steel Distribution, Inc. and Specialty Steel Supply, Inc. The PEP portfolio accounts for approximately $600 million in annual sales, or 25% of Carpenter's total annual revenue.

Heasley joins Carpenter after eight years with Steel Dynamics, Inc. (SDI), an $8 billion Fort Wayne, Indiana-based company for which he most recently served as Executive Vice President, Strategic Planning and Business Development, and President of Steel Dynamics' subsidiary, New Millennium Buildings Systems. Prior to joining Steel Dynamics as its CFO in 2005, Heasley spent three years as Senior Vice President and Manager, Metals Group for KeyBanc Capital Markets, Inc./ McDonald Investments.

In addition to SDI and KeyBank Capital Markets, Inc./ McDonald Investments, Heasley held corporate finance positions with Nakornthai Strip Mill Public Company Limited and Ernst & Young, LLP.

www.cartech.com

Abtex offers deburring system for Powder Metallurgy parts

The Tri Ten U Series has wheels for portability and deburrs both sides of green powder metal parts

Abtex Corporation, based in New York State, USA, includes in its range of Tri-Ten deburring systems a unit specifically suited to the deburring of green Powder Metallurgy (PM) parts.

The U series deburring system deburrs both sides of a part in a single pass and is designed for applications requiring a small footprint and portability.

Parts are loaded at one end and a magnetic conveyor passes them through an offset planetary deburring head where three fibre abrasive brushes deburr the upward facing surface.

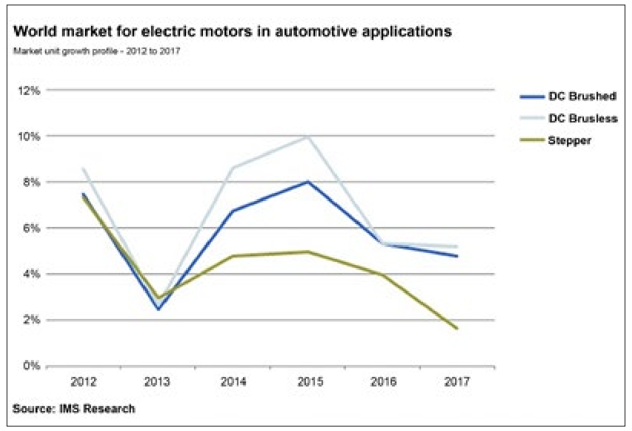
The conveyor then carries the part to a mechanism that flips it on to a parallel, magnetized conveyor that transports the part back through the planetary head and deposits it at an opening next to the entrance.

www.abtex.com

Increasing use of electric motors in automotive applications could provide boost for powder magnets

A recent study by IMS Research predicts that DC brushless motor shipments will outpace shipments of DC brushed and stepper motors used in automotive applications from 2012 to 2017.

DC brushless motor shipments are expected to increase by 52% over the 5 year period to reach more than 462 million units. This compares with 30% growth for brushed DC motor shipments for the same period. These predictions were published in the 2013 edition of the 'Electric Motors in Automotive Applications' market study issued by IMS Research earlier this year.



World market for electric motors in automotive applications (Source IMS Research)

Powertrain and chassis applications in cars have the highest usage rates for DC brushless motors. The predominantly mechanically driven applications such as power steering, transmission actuation and engine cooling systems are becoming increasingly electrically-driven, causing the number of DC brushless motors used in these applications to increase proportionately. DC brushless motors offer longevity and power density, qualities that are essential for use in powertrain and chassis applications where there is limited space and frequent motor operation is required.

"Although brushed DC motors account for a majority of the motors used in automotive applications, there is relatively less growth potential for brushed DC motor shipments," stated Bryan Turnbough, Small Motors Analyst at IMS Research. "On the other hand, DC brushless motors are being used in areas that are relatively new for electric motors in automotive applications, and that have been growing rapidly in recent years. Increasing sales of plug-in electric vehicles, which have powertrain and chassis systems that are electromechanically-driven, are expected to provide greater growth potential for brushless DC motor shipments than for brushed DC motors."

It is generally recognised that an increasing number of new DC brushless electric motors are made using powder magnetic circuits comprising a soft magnetic core made from bonded iron powder, and permanent magnets made from NdFeB magnets.

www.imsresearch.com

Japan Powder Metallurgy Association elects new president

The Japan Powder Metallurgy Association (JPMA) announced at its General Assembly that Mr Tetsuo Ito of Hitachi Chemical Co Ltd will take over as President of the association from Mr Kazuyoshi Tsunoda.

The JPMA also reported a number of changes to its board at the General Assembly held on May 23.

www.jpma.gr.jp

Mr Tetsuo Ito is the new president of the JPMA

High purity carbonyl nickel powders within specific size ranges offered by Hart Materials

Hart Materials Limited, a UK based supplier of metallic and composite particulate materials, is now offering a range of high purity carbonyl-based nickel powders within specific size ranges, currently not available in the market place.

Dr Tony Hart, Chairman of Hart Materials Limited, told *Powder Metallurgy Review*, "About four years ago the number of grades of carbonyl nickel powders available commercially was reduced to two specific products, one spherical powder and one filamentary product. Although these powders are very high quality materials the particle sizes currently available are not necessarily ideal for all applications. Hart Materials Limited has therefore developed technology to separate different size fractions from the basic spherical powder."

As a consequence the company is now able to offer three different size grades:

- > 44 microns
- < 44 microns > 20 microns
- < 20 microns

The company states that products can be supplied with accurate particle size details and a basic chemical analysis. Further developments are in hand to produce an even finer grade with 100% of particles below 15 microns.

Dr Hart is a former employee of what was the International Nickel Research Laboratory in Birmingham, UK, and has a sound appreciation of the advantages of carbonyl nickel powders. Dr Paul Lansdell, who has been heading up the development project, graduated in metallurgy at Birmingham University and was later awarded his Doctorate in electrochemistry by the same establishment.

www.hartmaterials.com

University of Trento successfully hosts EPMA's 2013 PM Summer School

The University of Trento hosted the latest EPMA Powder Metallurgy Summer School, which took place 8 - 12 July 2013 in Trento, Italy. The annual summer school, organised by the European Powder Metallurgy Association, provided 52 students from a variety of academic and industrial backgrounds with an introduction to PM by a number of highly regarded academics and industrial lecturers.

Professor José Torralba from the Universidad Carlos III de Madrid, coordinated the event in conjunction with Professor Alberto Molinari and his team from the University of Trento.

Lectures were complemented by the University of Trento's laboratory facilities and as part of the practical side of the event the students visited two companies; Mimest, who produce typical MIM parts, and Eurocoating, a company working in biomaterials. Participants also received complementary copies of both *Powder Metallurgy Review* and *PIM International*.

Joan Hallward, Summer School Coordinator stated, "This year's Summer School programme has benefited from the University of Trento's superb laboratory facilities and well located hotels. No Summer School would be complete without the Summer School dinner and song contest, where everyone sang to their heart's content."

www.epma.com

Participants at the EPMA 2013 PM Summer School

2014 PM World Congress set for Orlando, USA

The 2014 World Congress on Powder Metallurgy & Particulate Materials – PM2014 will take place at the Walt Disney World Dolphin Hotel, Orlando, Florida, USA from May 18–22 2014.

Organised and sponsored by the Metal Powder Industries Federation (MPIF) in cooperation with APMI International, PM2014 will be the most important international PM event of the year.

Along with an all topic technical programme a number of special subject areas have been identified for special interest programs, these include:

- NDT/Failure Analysis
- Machinability
- Fatigue
- Technologies for PM Growth.

A major trade exhibition will also feature international suppliers of metal powders, components, equipment and related services.

www.mpif.org

Hoeganaes launches smartphone app

Hoeganaes Corporation, a world leader in the production of atomised steel and iron powders based in Cinnaminson, New Jersey, USA, has recently launched a free app that brings the company's product data sheets directly to a user's smartphone or tablet.

The app includes data sheets for the company's Ancorsteel, Ancorbond, Ancorloy and Distaloy range of products, allowing the user to see alloy compositions, flow rates, compaction pressure data and more.

The Hoeganaes app provides data on a range of products

The app, currently available in Apple iOS format, also includes a selection of extended abstracts from technical papers presented by Hoeganaes, details of key regional contacts, and a list of industry events that the company is scheduled to exhibit at.

The app can be download from the Apple itunes store.

www.hoeganaes.com

3D Systems completes acquisition of Phenix Systems

3D Systems based in Rock Hill, South Carolina, USA, has completed its acquisition of Phenix Systems, a leading global provider of Direct Metal Selective Laser Sintering 3D Printers based in Riom, France. The company paid $15.1 million for 81% of the share capital and will seek to purchase the remaining shares and voting rights in accordance with the requirements of the French Markets Authority.

Phenix Systems designs and manufactures proprietary Direct Metal 3D Printers that print chemically pure, fully dense metal and ceramic parts from very fine powders with a particle size ranging from 6 to 9 microns. Materials include stainless steel, tool steel, super alloys, non-ferrous alloys, precious metals and alumina for a variety of aerospace, automotive and patient specific medical device applications.

"Phenix Systems is a strategic and differentiated addition to our extensive 3D content-to-print portfolio and we are thrilled to deliver these powerful solutions to our customers," stated Avi Reichental, President and CEO, 3D Systems. "Our proven track record in advanced manufacturing, combined with Phenix Systems extensive metals technology and expertise represents a true game-changer that empowers our customers to manufacture the future."

www.3dsystems.com

New Additive Manufacturing system for 3D printing of removable partial dentures

EOS GmbH recently showcased a new Additive Manufacturing (AM) process at the IDS 2013 (35th International Dental Show), Cologne, Germany, for producing removable partial dentures (RPD). The technique uses 3D data sourced directly from the patient's mouth as the basis for the manufacturing process.

Data created by intraoral scanners or from scanning an impression or model is processed without any loss of accuracy using the customised software functions of the new CAMbridge 2012 RPD module from 3Shape. The resulting virtual model is sliced and the digital information is utilised to direct a focussed laser beam to fuse metal powder in successive layers until the prosthesis is complete.

For a dental laboratory, the conventional manufacture of cast prostheses involves a lot of work. The preparation of a cast model and subsequent wax modelling often takes more than an hour and the entire casting procedure including finishing is time-consuming.

Typical removable partial dentures

Laser sintering in action producing crowns and bridges

The digital AM production method, by contrast, saves a lot of time, as the design for the RPD is ready in around 15 minutes. Due to the flexibility of design possible with Direct Metal Laser-Sintering (DMLS), the manufacturing process does not restrict the capabilities of the modelling software. High strength, rigid parts are produced.

The production of RPD's via DMLS is very accurate, making laboratory work easier. The denture is produced to an accuracy of ± 20 µm and is of a consistently high quality. Around 48 units can be produced within 24 hours, corresponding to an average build time of around 30 minutes per unit, making the process economical.

RPDs are made in the established EOSINT M 270 machine from EOS. Certified for use in the dental industry (CE 0537), EOS CobaltChrome RPD is the powder metal used. It is a fine grained, biocompatible material free from nickel, beryllium and cadmium. Its mechanical properties including density, resilience and elongation at break satisfy the requirements of the standard EN ISO 22674:2006 Type 5.

www.eos.info

Ipsen and ExOne collaborate to offer complete 3D printing solution

The ExOne Company, a manufacturer of three dimensional printing machines and printed products, is collaborating with vacuum furnace manufacturer Ipsen to provide customers with a complete 3D printing package.

ExOne expects its collaboration with Ipsen to strengthen the level of support offered to customers throughout the entire development and production process. Together the companies will provide a packaged turn-key solution for customers, enabling them to materialise new concepts, designs, prototypes and production parts with virtually unlimited design complexity.

The ExOne M-Print system selectively dispenses chemical binder into thin layers of powdered metal

David J Burns, ExOne's President and COO, stated, "As our pipeline of opportunities is building we have simplified the purchasing process for 3D printers by offering a complete printer-furnace package. Ipsen is ideal for us to collaborate with given their industrial focus and global presence."

"As technical experts dedicated to lean manufacturing, Ipsen was chosen due to our industry wide reputation for custom innovations and forward thinking research and development focus," stated Mark Heninger, Ipsen's Vacuum Product Manager. "We are excited about this collaboration, and the opportunity to pool our knowledge with ExOne to provide a reliable solution for customers."

ExOne builds 3D printing machines at its facilities in the United States and Germany. ExOne also supplies the associated products, including consumables and replacement parts, and services, including training and technical support, necessary for purchasers of its machines to print products.

Ipsen has production locations in Europe, America and Asia, along with representation in 34 countries. The company designs and manufactures industrial vacuum furnaces, atmosphere furnaces and supervisory control systems for a wide variety of thermal processing markets.

www.exone.com
www.IpsenUSA.com

European Powder Metallurgy Association elects new President

The European Powder Metallurgy Association (EPMA) has announced that Philippe Gundermann, CEO of Aubert et Duval, has been elected as the association's new President. Some 30 member companies met in Munich on May 3 2013 for the association's 24th Annual General Assembly.

At the General Assembly retiring President Ingo Cremer, Cremer Thermoprozessanlagen GmbH, presented a review of the last six years of his presidency. Gundermann then concluded, "We would like to thank Ingo Cremer for his work on behalf of EPMA over his last two-terms as President against some very difficult external conditions." Gundermann also outlined his vision for the future direction of the EPMA.

Jonathan Wroe, EPMA Executive Director, gave an update of the EPMA's activities over the past twelve months, reporting that the EPMA had a stable membership base and produced a better than anticipated positive financial result in 2012. "We are looking forward to further growth in both the PM industry and the association, where we will be assisted by the newly launched European Additive Manufacturing Group (EAMG)," he stated.

The EPMA Council was re-elected with two changes. Dr Rainer Link, GKN Sintermetals, replaces the retiring Volker Arnhold, and Jody Turin, Bodycote AB, joins the Council as the new representative for the HIP sector. Peter Kjeldsteen, Sintex A/S, was elected to take over as Treasurer.

Gundermann started his career in metallurgy 20 years ago in the non-ferrous sector, joining the ERAMET Group in the area of cobalt powder production. As CEO of Eurotungstene he developed knowledge in hardmetal technology and cobalt, copper, nickel and rhenium powder processing before being appointed CEO of Erasteel in 2007, and then Aubert & Duval in 2009. Here he maintained a strong focus on superalloys and high-speed steel powders as well as hipped parts.

Retiring President Ingo Cremer was elected in 2007 as the fourth President of the EPMA following Cesar Molins, Lothar Albano-Müller and Per Lindskog.

www.epma.com

Retiring EPMA President Ingo Cremer with new President Philipoe Gundermann and former President Cesar Molins

Höganäs Digital Metal® produces highly complex and intricate designs with 3D printing

In November 2012 Swedish metal powder producer Höganäs AB acquired fcubic AB as part of the company's vision to broaden the application of powder technology. The acquisition included primarily patents, expert knowledge and a first generation 3D printer for metal components. The company name was then changed to Digital Metal AB. A process line has since been built up in Höganäs for production with 3D technology and a second generation 3D printer is currently being commissioned.

Digital Metal AB, states Höganäs, offers a revolutionary and innovative manufacturing technique for metallic components. It is a proprietary technology for the Additive Manufacturing and 3D printing of metal components and systems and offers the unique capability to cost effectively produce highly complex and intricate designs and features for metallic parts.

Additive Manufacturing is the process of building components in layers directly from 3D CAD data, without the need of complex and costly tools and with minimal waste material. The technology is currently in the process of moving from a focus on the production of prototypes to the rapid manufacturing of series components.

Whilst most of the revenue derived from the technology to-date can be attributed to production of plastic parts, the production of metal parts by 3D printing is becoming more and more viable. The main methods for Additive Manufacturing of metal parts include laser or electron beam melting or precision ink-jet processing on a powder bed. The advantages of 3D technology are primarily;

- Free forming capability with few design limitations
- Fast time to market - only a 3D file is needed to create a prototype
- Low initial cost as there is no tooling

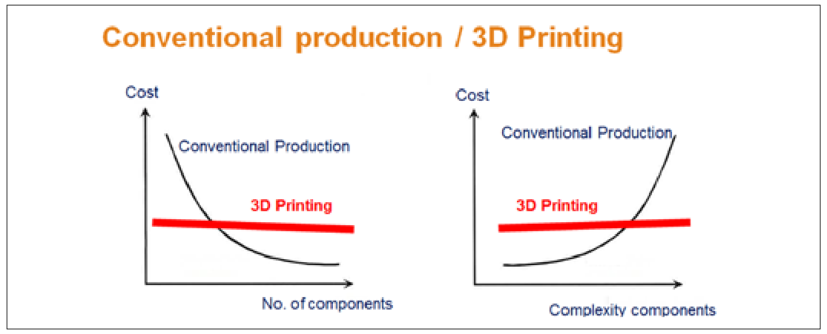


Fig. 1 The cost benefits of additive manufacturing

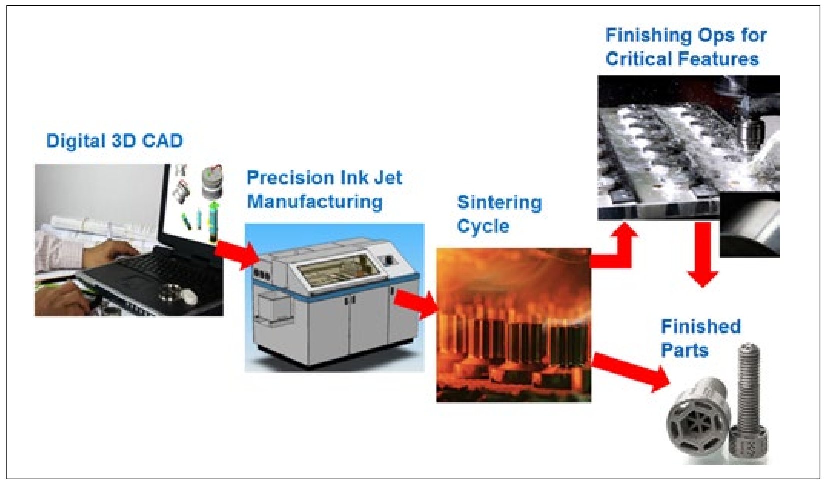


Fig. 2 Overview of the Digital Metal® process

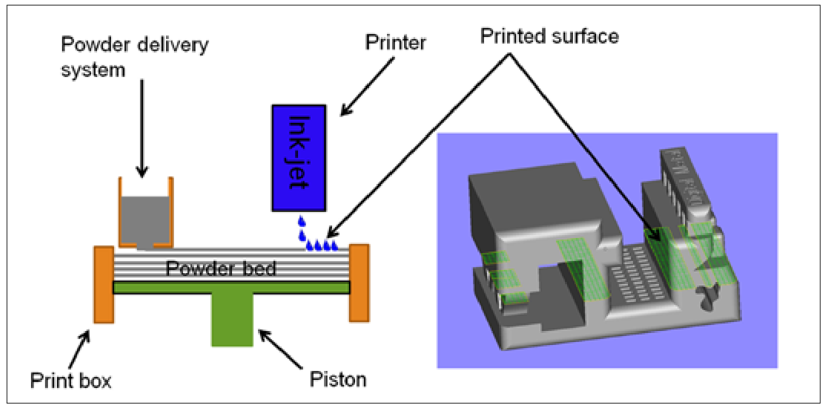


Fig. 3 Schematic of the Digital Metal® printing process

- Easy customisation - multiple 3D files can be handled simultaneously corresponding to multiple customer needs.

The graphs in Fig. 1 show schematically the cost benefit of Additive Manufacturing. The initial start-up cost for conventional production is, in general, high due to tooling or the setup of CNC machines, however the cost per component will be reduced with volume production. 3D printing only needs a CAD file to start production providing a low initial cost. Some cost improvements can be achieved with volumes due to improved post treatment steps. Another cost difference with Additive Manufacturing is that the process is, in general, not restricted by shape complexity, unlike conventional technologies. The more challenging the shape, the more advanced the tool has to be in order to make a part with conventional processes. This has a substantial impact on cost development.

The Digital Metal® process

Höganäs' Digital Metal® system is based on precision ink-jet printing on a powder bed. Components are built up layer by layer from an original 3D or CAD file. The 3D file is prepared and sliced into 2D files corresponding to a 45 micron powder layer. A layer of 45 micron powder is applied in the build box and the printer passes over the surface and puts ink on relevant spots based on information from the 2D file.

This is repeated layer by layer until the component is formed in accordance with the original 3D file. Building time is currently in the region of one cm per hour, however it takes just as long to print the build box whether it contains one component or is full of components.

Finishing after printing includes the cleaning of components from powder residue and sintering to achieve the final size and strength. Surface roughness after sintering is normally Ra 6 but can easily be improved with traditional surface treatment processes to Ra 3 or better.

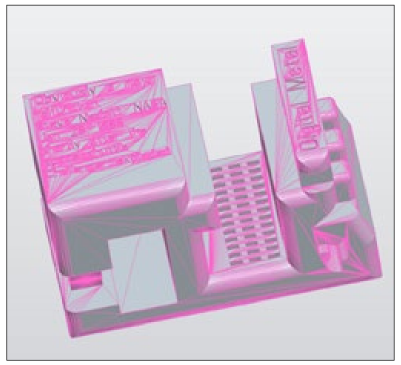


Fig. 4 A typical CAD file as used in the Additive Manufacturing process

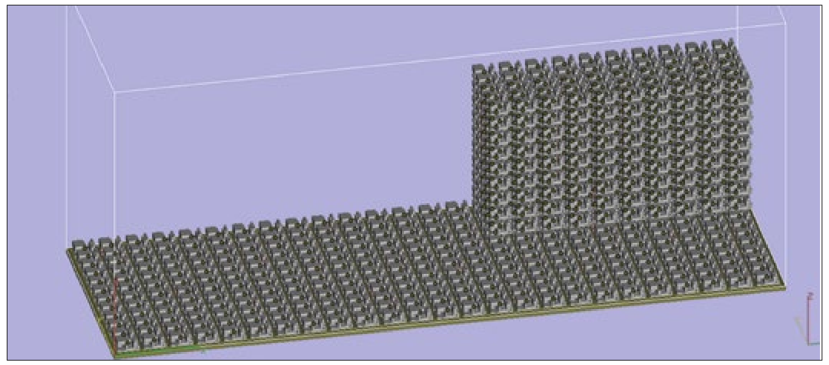


Fig. 5 Schematic of the build box that shows the potential to build a large number of components in a single process

Benefits of Digital Metal® technology

Printing is done at room temperature with Digital Metal® technology without partial melting of the powder particles, which occurs with competing laser or electron beam technology. This provides high tolerances, a high level of surface finish and very high levels of detail. The technology offers tolerances of 100 microns, with holes and wall thicknesses currently down to 200 microns.

Cleaning of printed components is facilitated by the formation occurring at room temperature. Furthermore, there is in principal no need to build a support structure during printing because the components are supported by the powder bed in the build box. The whole volume of the build box can therefore be maximised and the components can be packed tightly because no account of thermal conductivity needs to be taken.

The process is flexible since forming and sintering is done in separate steps with different equipment, which means that the forming step can be maximized.

Markets

Höganäs states that its Digital Metal® technology is most suitable at present for small components of complex shape for prototype or series production for various market segments including non-critical components in the aerospace and medical sectors. Examples of different components manufactured by Digital Metal® technology are shown in Figs. 6 to 8.

www.hoganas.com

Fig. 6 Very high resolution is possible to obtain with Digital Metal® technology. Miniatures of the old salt glazed pottery Jars were produced for Höganäs' annual meeting in 2013. Surface conditions are Ra 6 as sintered or Ra 1 as super finished

Fig. 7 The advantages provided by Digital Metal® have been used to produce lightweight fasteners from 316L stainless steel. The threads are printed without any additional machining. The hollow interior structure would be very challenging to produce with conventional technology

Fig. 8 The design freedom offered by this technology enables design for function. These sensor housings, with pressure membrane and threads, are printed simultaneously with no post machining

North America's PM industry: The challenges of an evolving automotive market

In the 1990s North America's Powder Metallurgy industry enjoyed rapid growth thanks to a dramatic increase in the quantity and weight of PM components used in US automobiles. The recession of 2008, a drive towards smaller and more fuel efficient vehicles and the globalisation of engine and gearbox development has however dramatically changed the landscape for the region's PM producers. Eric Boreczky reviews the recent history of PM in North America and considers the challenges that lie ahead in adapting to a changing automotive market.

Over the last fifty years the North American Power Metallurgy (PM) industry has evolved from a low cost metalworking technology producing simple parts (based on today's standards) to a multi-billion dollar industry producing highly complex metal parts and assemblies. The PM industry has grown along with the automakers to become a partner with OEMs, meeting the product challenges of the marketplace as automakers continually create new cars and trucks to satisfy consumer demand, adhere to government regulations and manage the changing complexity of a globalising marketplace.

From iron bearings, transmission clutch plates, suspension ball joints and engine oil pump gears weighing just a few ounces, the PM industry has developed the technology to produce highly complex, special alloyed parts such a powder forged connecting rods, multilevel transmission carrier frames and engine VVT components (Figs. 1 & 2) while continually improving the price and performance of "mature" parts to meet new PM application performance targets. These new applications, and the efforts to improve existing parts, has helped to grow the industry from 3-5.5 kg (7-12 lb) of PM content per vehicle to a North American vehicle today containing nearly 20 kg (45 lb) of PM parts per vehicle on average, with some vehicles containing over 34 kg (75 lb) of PM content. Current applications include dozens of critical engine, transmission, driveline and chassis applications.

The Metal Powder Industries Feder-

Fig. 1 Components such as this carrier and one-way rocker clutch assembly made for Ford Motor Company by GKN Sinter Metals, USA, have helped grow the PM industry (Courtesy MPIF)

Advantages of the PM Process

- Eliminates or minimises machining by producing parts at, or close to, final dimensions
- Eliminates or minimises scrap losses by typically using more than 97% of the starting raw material in the finished part
- Permits a wide variety of alloy systems
- Facilitates manufacture of complex or unique shapes which would be impractical or impossible with other metalworking processes
- Is suited to high-volume component production requirements
- Is cost effective

Fig. 2 Powder Forged connecting rods continue to offer growth opportunities for the PM industry. This fracture split con-rod is manufactured by Metaldyne, USA, who manufacture more than 50 million connecting rods per year at various locations throughout the world (Courtesy MPIF)

ation (MPIF), North America's PM trade association, recently reported that the PM parts content in the typical US-made car can be as high as 1,000 individual parts representing 325 applications, with total weight increasing slightly to 20.18 kg (44.5 lb) this year. This compares with 19.95 kg (44 lb) in 2012, which itself increased

> *"The success of PM in the automotive industry is driven by the inherent advantages provided by the PM process over other metalworking technologies"*

0.90 kg (2 lb) from the previous year. In contrast, the PM content in the typical European-built car remained even last year at 8.79 kg (19.4 lb), while the PM content in the typical Japanese car declined slightly to 9.07 kg (20 lb).

The success of PM in the automotive industry is driven by the inherent advantages provided by the PM process over other metalworking technologies. The automakers and suppliers needed a low cost, reliable metalworking technology that could make millions of parts with little part to part variation. PM has proven itself over decades by meeting these basic criteria in which both the buyers and sellers of PM parts have benefited.

For many years, the PM selling cycle consisted of two levels - selling the PM technology and then selling the part. Even with PM's success in providing cost effective metalworking solutions, with each new generation of design engineer the selling of the technology continues because of its limited academic exposure compared to other processes.

Automotive PM's growth in the 1990s

As reported by the MPIF, the region's PM industry is heavily weighted to the automotive market, with about 73% of the structural PM components produced being incorporated into North American cars and trucks. PM consumption in North America closely tracks auto production (Fig. 3). This strong relationship created an environment in which to develop new materials, new processes, new equipment technologies and develop new part applications that has provided an opportunity to obtain a reasonable return on investments for these R&D efforts. The increasing demand led to significant growth in capacity investment for materials and equipment, as well as process improvements to help meet demand and the introduction of new technologies. This in turn led to the formation of many new PM companies, and a significant expansion of existing companies, throughout the 1990s.

Another way to look at PM's value in the automotive marketplace is the weight per vehicle benchmark (Fig. 4). Over the last 30 years, PM content per vehicle has grown from ~7.25 kg (~16 lb) per vehicle to ~20 kg (~44 lb) estimated in 2012, an impressive 275% increase since 1980. There was a significant PM growth spurt in the 1990s with PM per vehicle in 1990 at about 10.8 kg (24 lb) per vehicle climbing to ~19.05 kg (~42 lb) in 2002, a 175% increase. This per vehicle increase, and the overall powder consumption increase, was due to a number of factors: the growth in auto production; a shift from lower PM content cars to much higher PM content trucks and SUVs; and the significant expansion of new PM part applications.

A new era in PM engine applications

PM applications grew dramatically supporting the rise in automotive PM consumption during the 1990s. They included Powder Forged (PF) connecting rods, crankshaft main bearing caps, engine valve guides and seats in aluminium heads, engine timing sensor rings, and engine stainless steel exhaust flanges and Hot Exhaust Gas Oxygen (HEGO) sensor components. PF connecting rods which typically weigh about 0.45 kg (1 lb) each increased consumption by the end of the decade to over 30,000 short tons per year. Main bearing caps weighing over 1.13 kg (2.5 lb) added about 1.8–4.5 kg (4-10 lb) per engine on about 20% of the engines built by the end of the decade. To improve the electronic engine controls, the use of PM engine sensor rings increased dramatically because they provided cost effective parts yielding complex designs and providing electronic pulse reliability. Although the weight of PM valve guides and seat inserts was not significant individually, the total volume demand per engine and the ability to fine tune the material composition made PM a great design selection.

Automatic transmissions

The automatic transmissions designed and produced in North America expanded the use of PM on a numerous critical parts as transmission torque converter hubs, transmission parking hubs, sprockets, variable vane pump stators, rotors, body and face plates. On a typical automatic transmission these components could add 2.75–8.15 kg (6-18 lb) per transmission. Most of these components were converted to PM because of improvements in material systems, part fabrication techniques and equipment advances, providing net or near net shaped parts requiring minimal secondary machining.

PM in 4WD systems

A third application system which PM usage significantly benefited was four wheel drive (4WD) transfer cases. The 4WD volumes increased in the 1990s as the sales of pickup trucks and SUVs increased dramatically over conventional cars. These 4WD transfers cases incorporated 3.6–6.35 kg (8-14 lb) of PM per assembly. The primary applications included sprockets, hubs, gears, oil pump rotors, planetary carrier frames and synchroniser rings.

The stabalisation of growth

In the 2000s PM consumption and weight per vehicle consumption stabilised in the 18–20 kg (40-44 lb) range as auto industry production peaked to 17 million unit levels. The emphasis shifted from mainstreaming new automotive technologies being introduced to meeting customer demand, maximising automobile production capacity and the automakers propping up sales with significant discounting and implementing severe supplier cost reduction strategies which de-emphasised new product and process developments.

There were, however, a number of PM part innovations that grew over the 2000s which included the significant application of PM hydraulic Variable Valve Timing (VVT) rotors, stators and housings in engines; the proliferation of automatic transmission planetary carrier frames; and automatic transmission mechanical one way clutch components mostly used in six speed transmissions. These new products offset the lost PM consumption due to design changes of various PM parts on some engines and the increase of foreign automaker market share gains in which these automakers used considerably less PM content compared to the domestic automakers.

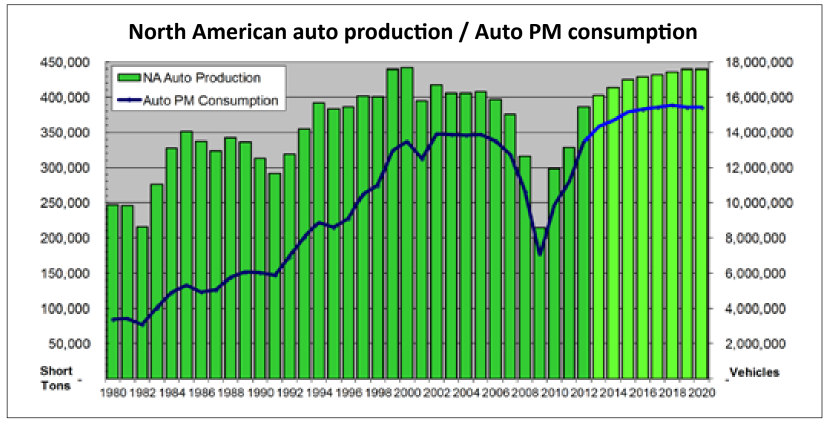


Fig. 3 PM consumption in North America closely tracks auto production (Auto data courtesy WardAuto/AutomotiveCompass)

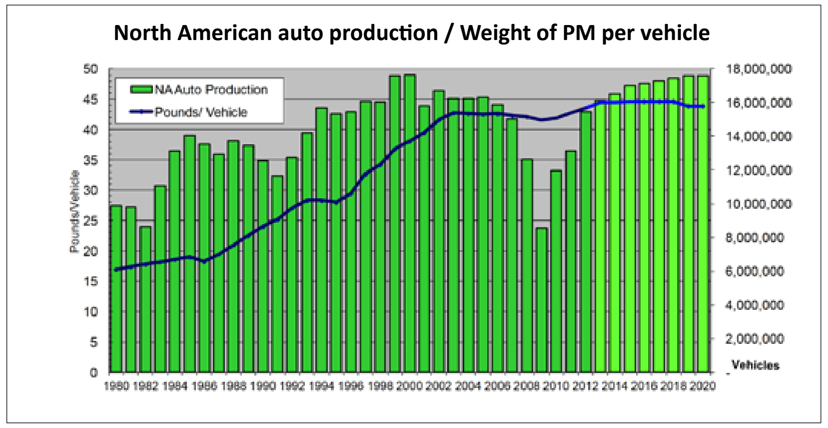


Fig. 4 Weight per vehicle has increased over the last 30 years and was estimated at around 20 kg (44 lb) in 2012 (Auto data courtesy WardAuto/AutomotiveCompass)

Then the recession of 2008-2009 and its impact

The impact of the 2008 recession and the collapse of the auto market in 2009 dramatically changed how the automotive industry now views the marketplace and the way they conduct their business. Many changes taking place in the automotive industry are having a direct impact on the PM industry supporting the automakers, some of which are being felt today while others are yet to be determined. One major impact is the current strong rebound of vehicle production volumes and the strong forecast for the future, and the ability of many suppliers without adequate capacity to meet this increase in demand. This is due to some companies downsizing and now being reluctant to add capacity, while others are introducing new products and require new capital for these products. This situation has created a new approach to how products are introduced, priced, and how supplier/customer relationships are being defined.

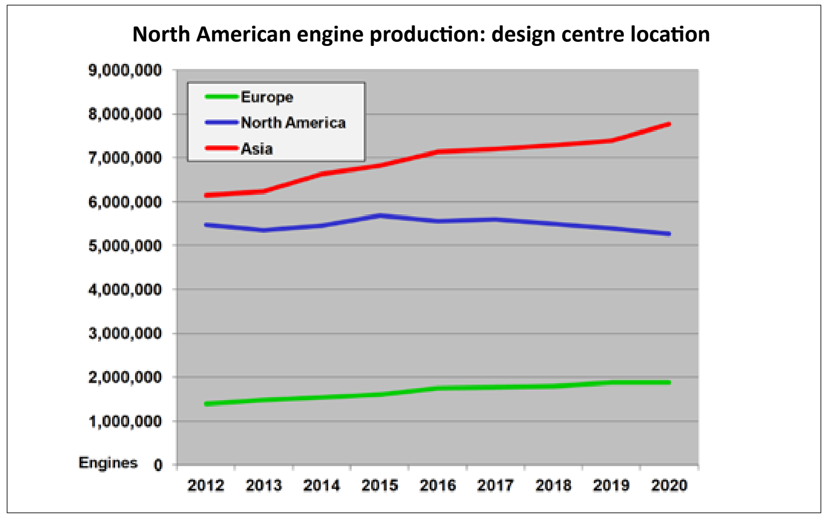


Fig. 5 The location of the design centres responsible for designing the engines that are manufactured in North America is predicted to change (Auto data courtesy WardAuto/AutomotiveCompass)

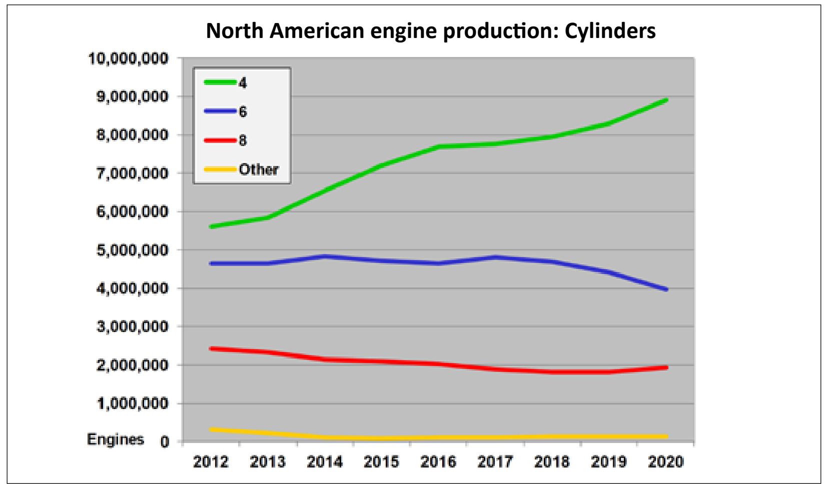


Fig. 6 Four cylinder engine production is predicted to rise in North America (Auto data courtesy WardAuto/AutomotiveCompass)

Another change in the auto industry is the new fuel economy standards being implement by the US. These new requirements are changing everything about the vehicle: the vehicle size and material options; powertrain design and the globalisation of design and production. Then add the equalisation of product quality of the automakers; the changing demands and demographics of the consumer and a number of other cultural changes. This has created a need to redefine the automotive business model which will require continued business adjustments as the marketplace evolves. The good news with all this change in the automotive industry is that it creates significant opportunities for those that are flexible and responsive to meet these new demands with new products.

New powertrain trends

The powertrains being developed by the automakers are changing the PM supplier landscape and they are doing it on a global basis with shorter design cycle changes. Even though most of the engines and transmissions are being produced for use in North America, more of the design and development work is being done overseas in European and Asian technical centres which historically limited the application of PM technologies compared to the current North American design centres (Fig. 5).

Based on reports by IHS Automotive, future North American engines will shift to smaller more powerful units. Most four cylinder engines that will be produced in North America have or will have their design roots in European and Asian engineering centres. North American engine design will focus on V6 and V8 engines. With about 45% of the current engine production in North America being designed in North America, it is estimated that this will shrink to ~35% by 2020 as the four cylinder engine market grows and the V6 and V8 engine market share continues to shrink (Fig. 6). This reduction in the number of engine cylinders will have a negative impact on future PM consumption. Such a shift will require fewer PM components and will demand new and more challenging design requirements of the existing parts and new parts being designed.

On the positive side, more foreign auto manufacturers are significantly expanding engine production in North America to support domestic production and some of these engines are targeted for export. This increased engine production will provide local sourcing of many PM parts for companies positioned with design and development resources overseas to support the production demands created in the North American market.

Gasoline engines

North American gasoline engine production trends forecast a shift to fewer engine cylinders, VVT technologies, direct fuel injection, turbo charging or supercharging, start/stop systems and a shift to electrical accessory systems such as power steering, water pumps and oil pumps. Ford, GM and Chrysler are expanding the use of many of these technologies to meet 2016 US CAFE Standards and will require the automakers to reduce engine weight and significantly increase engine performance with a smaller engine package. This "power density" shift adds significantly more stress and demands on many of the current PM components such as connecting rods, sprockets, valve guides and inserts and other related components. These changes will require better material properties, improved dimensional accuracy and more challenging durability cycles while still meeting commercial issues of the automakers and PM parts suppliers. In addition, many of these new engine systems will use PM components which should offset most of the losses incurred with the engine downsizing forecasted.

Diesel and alternative power systems

Alternative power systems such as hybrid and diesel engine are not meeting the volumes as numerous trade reports originally suggested but will satisfy niche consumer markets (Fig. 7). These hybrid and diesel engine types use significantly less PM content than typical North American gasoline engines. Based on various trade forecasts, most of these alternative power systems are expected to be imported unless there is a significant consumer increase to these technologies.

Uncertain future trends in PM automotive transmission applications

North American transmission design trends are going to have a major impact on PM applications, just as engines are changing with new design and production strategies (Fig. 8). Over the last five years, there was shift from 4 and 5 speed automatic transmissions to 6 speed transmissions and the next five years will shift again to 8, 9 and 10 speed automatic transmissions (AT), Continuously Variable Transmissions (CVT) and dual clutch transmissions (DCT). The older 4 speed transmissions contain 3.5–10 kg (8-22 lb) of PM content, the domestic automakers 6 speed transmission manufacturers contain up to 16.5 kg (36 lb) of PM content but some preliminary reports suggest the PM content of the new 8, 9 and 10 speed automatic transmission may contain considerably less, but this is not confirmed. CVTs are gaining production momentum on smaller cars and are replacing conventional automatic transmissions. Typical PM content is usually in the range of 1.8-4.5 kg (4-10 lb), significantly less than conventional automatic transmissions. European designed DCTs contain more PM content than CVTs but usually contain less than domestically designed automatic transmissions. PM content for DCTs is estimated to be in the range of 2.75-8.25 kg (6-18 lb).

PM content success in the automatic six speed transmission was due to a combination factors. GM and Ford co-developed their six speeds and have had success with PM in their earlier transmission versions; PM technology has advanced significantly providing cost effective design solutions for a number of new design features used in the new six speeds; and many of

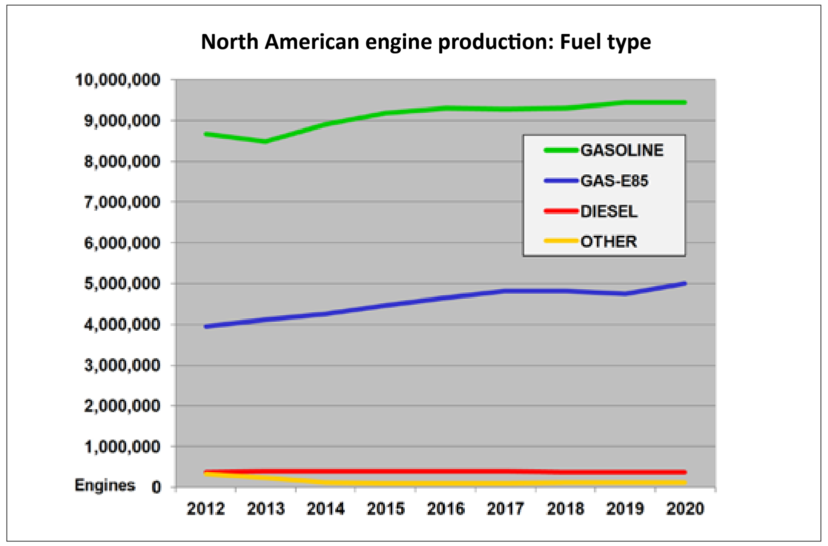


Fig. 7 Gasoline engines are still expected to dominate the North American market (Auto data courtesy WardAuto/AutomotiveCompass)

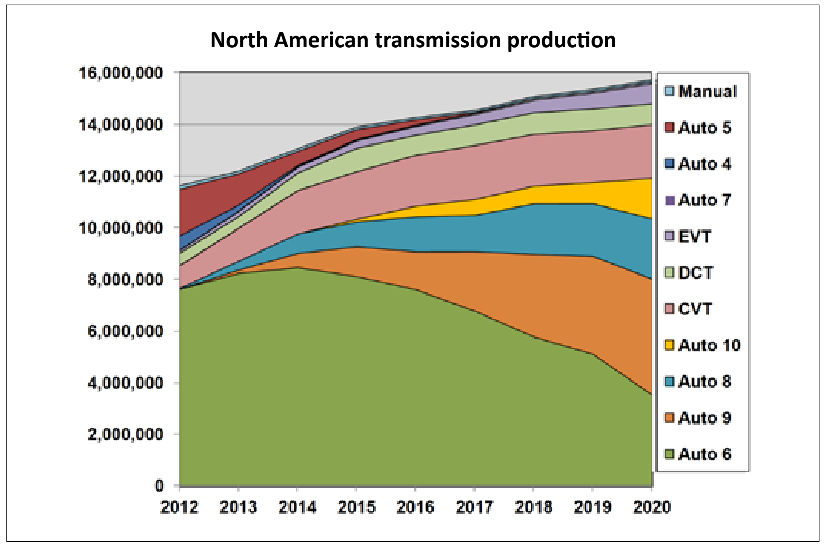


Fig. 8 Transmission design will have a major impact on PM applications (Auto data courtesy WardAuto/AutomotiveCompass)

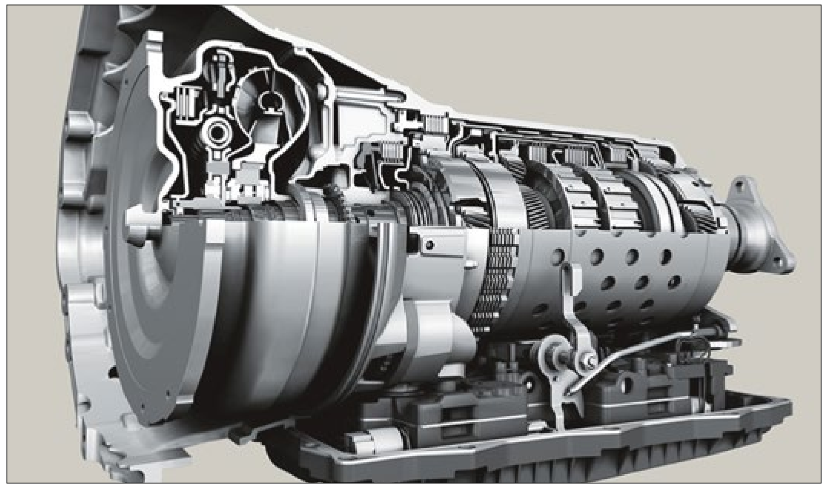


Fig. 9 This automatic 8-speed transmission from ZF is based on a completely new transmission concept. Such developments could offer significant new application opportunities for PM components (Image courtesy ZF Friedrichshafen AG)

the early designs were defined using PM driven by numerous end user focused PM education programs. Key components used in many of the new transmissions are oil pump components, carrier frame assemblies, one way clutch components and other parts.

Future automotive PM trends

Although the short term PM business outlook is strong, the long term automotive outlook for North America appears rather uncertain. Over the last 40 years the PM industry has been driven by an entrepreneurial spirit which was supported by numerous part application opportunities; a relatively low cost of entry in the parts making arena and continuing material and process innovations.

"...the current trends suggest even with major vehicle downsizing and powertrain design changes, PM content should remain in the range in the 17-19 kg per vehicle"

Many of the existing applications have become "commoditised" with many of the same parts being re-sourced to different companies driven by lower prices and usually lower profit margins to the point that many of these applications provided very small profit margins but offered capacity utilisation of existing equipment and marginal cash flows, particularly in the mid-size press range for those companies with the lowest price. These low ROI parts limited reinvestment for many smaller PM fabricators. But larger companies owned by holding companies or financially stable global parent companies were able to reinvest in new part applications and support this business by providing the capital to grow the market. The financial stress of this situation was significantly compounded by the recent North American recession. The good news was the strong automotive recovery benefited those companies with significant new business developed efforts prior to and during the recession and the financial support to expand operations to support the North American automotive recovery over the last three years.

This new North American automotive business model is shifting from making parts at any price to selectively targeting part family applications with significant business potential yielding predetermined financial results. This strategy is bringing to market large, more complex parts using more specialised materials, more complex processes and more control of secondary operations by the parts makers. This technology shift creates new opportunities for companies that have global sales and product development networks to design PM parts wherever any new engine and transmission designs are being developed and to produce them in their North American facilities. Those North American focused companies that try to convert wrought type parts developed overseas (which typically do not use PM components as illustrated in PM content in European and Asian vehicles) will have limited success and the conversion success that does occur will more than likely be the result of discounted prices. How successful this global development strategy evolves will determine the direction of future automotive PM content in North America. In the meantime, the current trends suggest even with major vehicle downsizing and powertrain design changes, PM content should remain in the range in the 17-19 kg (37-42 lb) per vehicle range through the rest of the decade.

Another way to increase the rate of PM consumption in the North American automotive market beside the current activities is to reactivate efforts to develop "PM Champions" to promote PM technologies within the auto companies and the major Tier 1 suppliers. Besides the market conditions of 1990s which nurtured the increases of automotive PM content per vehicle, these "PM Champions" served as an strong partners to advocate PM technologies within the domestic "Big 3" and created collaborative relationships from which both the automakers and PM industry benefited by supplying and using cost effective metal components. Developing a new generation of "PM Champions" would not only serve to help develop traditional uniaxially compacted parts but would also aid in the use of MIM parts and other PM technologies.

Finally, to increase the use of PM not only in North America and the rest of the world, the regional PM trade associations should consider collaborating more aggressively in the globalisation of the automotive technologies in order to support the global automotive automakers and their key suppliers. This collaboration could begin with a global market evaluation of various PM technologies in the automotive market, focusing on the similarities and differences as they relate to each region and country. The process could identify high benefit opportunities for major global PM companies and regionally focused companies with the goal of increasing PM content for all member companies.

Finally, many believe that the automotive conventional PM market is in decline, particularly in North America. If the industry continues on its current path, this "doomsday trend" is possible. But to survive and prosper, rational change is needed to adjust for the changing global automotive industry and to proactively create a logical plan driven by good market research and an honest understanding of existing and new business opportunities. Except for a handful of powertrain applications, most automotive PM parts have market shares well under 50%, usually in the range of 30%. If there was an emphasis on converting more developed parts to PM this new business could offer continued growth in North America.

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Plansee Seminar 2013: The global refractory metals and hard materials industry meets in Austria

The 18th Plansee Seminar organised by the Plansee Group was held in Reutte, Austria, from the June 3-7 2013 and attracted more than 500 international participants specialising in refractory metals and hard materials. In this exclusive report for *Powder Metallurgy Review*, Dr Leo Prakash reports on presentations highlighting global R&D trends and the phenomena of cobalt capping.

The first Plansee Seminar, focusing on the science and technology of refractory metals and hard materials, was organised by Prof Paul Schwarzkopf in 1952. The event has steadily grown in both size and prestige to become the premier global event for this important industry.

This year's seminar boasted 123 accepted contributions in the field of refractory metals and 144 in the field of hard materials. The 109 oral presentations, special interest seminars and poster sessions drew large crowds at all times.

Starting with global overviews of the PM markets and R&D trends, the presentations addressed nearly all disciplines in this industry, from innovations in powder production to processing, materials and their applications, from modelling and characterisation, and the important topic of recycling.

Our series of reports begins with a summary of a keynote paper presented during the opening session of the seminar focussing on global research and development trends in the hardmetals industry.

Global R&D trends in the PM hardmetals industry

Prof Dr Susanne Norgren and co- authors J Garcia, A Blomqvist and L Yin, from the Sandvik Group, in their comprehensive review paper, confirmed that cemented carbide is still the undisputed leading cutting tool, wear part and rock drilling material and presented work carried out in recent years on fine grained material, interfaces, alternative binders, alternative sintering techniques, gradient structures, high resolution microscopy and electron back scatter diffraction. They noted that among emerging trends, coupling between experiments and modelling at different length scales has been growing, as

Fig. 1 Delegates during the opening session of the Plansee Seminar (Courtesy Plansee)

well as three dimensional modelling of microstructure evolution.

As an introduction, some market data based on the ITIA 2011 Statistical Overview of Supply and Demand [1] was presented by Norgren. "The total global tungsten market demand was 79,600 tons and if recycling was also included the actual consumption would have reached 103,500 - 111,500 tons. Out of this, 47,500 tons was consumed by the hardmetal industries, not including recycling [Table 1]. If a 30-40% use of recycled material is assumed the total tungsten consumption for hardmetals would have been around 61,750 - 66,500 tons, of which approximately 45-50% would have been submicron tungsten carbide."

Not only is tungsten consumption in China continuing to grow faster than in rest of world and is now 47,000 tons/year, some 59% of the world consumption, but this is accompanied by widened research and development activity as well. Due to the higher prices for tungsten raw materials, new mines outside of China are expected to be opened and the pressure to recycle tungsten will continue to grow for both hardmetal producers and users, explained Norgren.

The authors estimate that submicron grained grades now make up almost 50% of the world tungsten carbide market and anticipate that this trend will continue to increase, not only due to a strong trend for miniaturisation, for example, smaller computers, phones etc., but also due to new and better Physical Vapour Deposition (PVD) techniques which have widened the use of PVD coated metal cutting inserts and rotary tools. On the other hand, rising metal consumption and associated mining activities have maintained a steady demand for hardmetal rock drilling tools, which are mainly coarse grained in microstructure. Furthermore, the production of cemented carbides for metal cutting remains an important segment of the industry with incremental improvements in the fifty year old CVD coating technology. In this area, improving coating texture and modelling of substrate surface gradient formation are hot topics of interest.

Modelling at different dimensional length scales is now a basic part of product and grade development in the drive to create better products. Atomistic and thermodynamic modelling mutually contribute to the understanding of interfaces and interface structures. This is very relevant for submicron grades where the properties to a large extent are governed by the interfaces.

R&D trends

Selected topics discussed in this review are thermodynamic and kinetic modelling, submicron cemented carbide (focussing on the interfaces and inhibitor interfacial layers), alternative binders, gradients, solubilities in WC and modelling in manufacturing processes and product applications.

Thermodynamic and kinetic modelling

The several examples given in the area of thermodynamic and kinetic modelling clearly promote our understanding of the fundamentals behind how cemented carbides achieve their properties whether in bulk or as gradients. Firm predictions of not only stability regions, melting ranges, carbon balances, recipes and other properties are available from the Thermo-Calc database software for phase diagrams for many hardmetal systems. However, thermodynamic databases are never better than the experimental data on which they are based and here it is appropriate to emphasise that some fundamental questions still remain unanswered even in the ternary W-C-Co phase diagram and we still have some way to go in spite of the diffusion models and *ab initio* calculations.

Interfaces

The importance of interfaces is known and special attention on their characterisation has found acceptance, especially in the field of fine grained hardmetals. Examples of how Atom Probe Tomography (APT), High Resolution Transition Electron Microscopy (HRTEM) as well as thermodynamics and *ab initio* calculations have helped to gain understanding on how the interfaces are structured and affected by inhibitors have been published in the last ten years.

It can be safely incurred that thin films are present between the WC grain boundaries, their occurrence depending on the composition and grain orientation. Calculations show that thin films inhibit grain growth by the nucleation and growth of new interlayers, not by inhibiting diffusion through the liquid binder. It comes as no surprise that the creation of an interlayer reduces the energy of the system. An example of a measured interlayer of $CrC_{(1-x)}$ is shown in Fig. 3.

Fig. 2 There were a number of poster sessions to accompany the oral presentations during the Plansee Seminar (Courtesy Plansee)

	Europe	Japan	USA	China	Russia
Hardmetals	72%	75 %	66%	54 %	70 %
Steels/Superalloys	9%	12 %	9%	28 %	14 %
Mill Products/Lighting	8%	6 %	20%	11 %	16 %
Chemicals and Other	11%	7 %	5%	7 %	0 %

Table I ITIA 2011 Statistical Overview of Supply and Demand, the percentage of the W used by different market areas [4] (Courtesy Plansee)

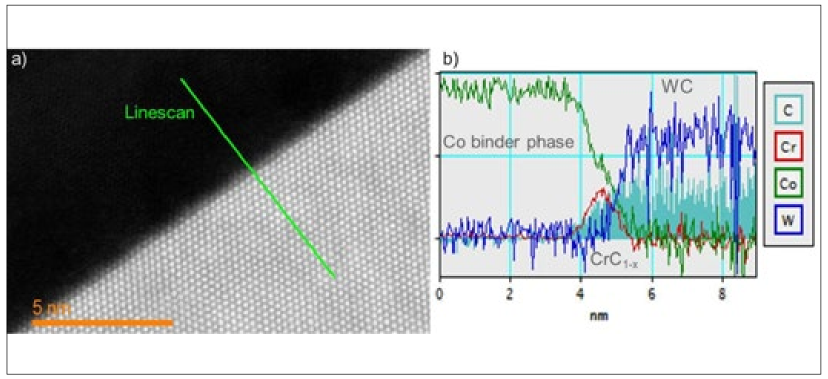

Fig. 3 (a) Atomic resolution STEM image of a WC-Co interface showing a thin $CrC_{(1-x)}$ layer in a WC -10 wt%Co -1.0 wt% Cr grade. (b) Extracted intensity profile from STEM-EELS line scan across the interface as marked in (a) (Courtesy Martina Lattemann, Sandvik Coromant) [4]

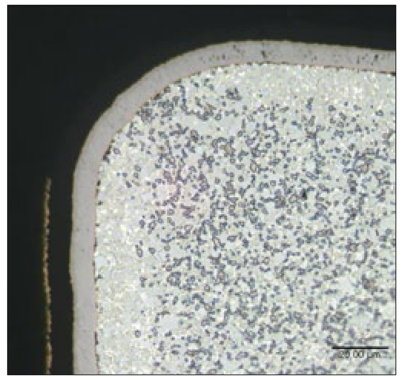

Fig. 4 Gradient sintered hardmetal. Typical steel turning grade in the P25 regime [4] (Courtesy Plansee)

Solubilities in WC

Solubilities in and doping of the WC crystal has found renewed interest and it can be concluded that *ab initio* calculations are in sync with experimentally measured values.

It was already known that molybdenum is the only metallic element that has a known solubility in the WC lattice, current research shows that other than Cr with a maximum solubility of 5 wt%, all other studied elements like V,Ti, Mn, Ta. Nb, Co, Hf, etc. exhibited very limited solubilities in hexagonal WC in the range of 10^{-3} to 10^{-5}. (W,Al)-C-Co composite cemented carbides are also of interest and it is reported that the content x of Al in the $(W_{1-x}Al_x)C$ phase could vary between 0.2 and 0.6.

REACH and alternative binders

REACH, so far, has classified cobalt as very toxic for human health [2]. Also, the US National Toxicology Program, NTP [3], states that the tungsten carbide-cobalt hardmetal dust has been shown to be more toxic in combination than either pure cobalt or tungsten carbide alone.

There has been a flurry of activity to find alternatives to the cobalt binder in hardmetals, not only since the spectre of REACH has become reality. The potential health risk of inhalation of hardmetal raw powders and dust in the cemented carbide industry production lines has been studied by different organisations and the results could be a cause for concern. The alternative to cobalt as a binder is either iron based or nickel based. From the health and safety aspect, nickel based alloys do not offer any advantages, though they do exhibit a good combination of properties, if tailored to the application.

A vast body of past and current literature on the pros and cons of using iron as an alternative binder exists and shows that replacing cobalt by application tailored iron based grades is possible, but also that more research work on alloy design and quality control issues are necessary.

Gradients

Gradient cemented carbides allow tailoring important properties such as stiffness and toughness in a single hardmetal component in different areas such as skin and core. Established gradients in the cemented carbide industry are the so-called γ-phase-free gradients for metal cutting applications and macro-gradients for rock tools applications . However R&D publications on development of γ-phase-free gradients in cemented carbides have become fewer over the last decade. A reasonable explanation is the increased focus on the development of novel CVD and PVD coatings for machining applications, especially relating to coating composition, nanostructure, adjustment of texture, residual stress, post treatment processes and bonding between layers and layer to substrates and more.

Current research mainly focuses on the production, characterisation and modelling of either γ-phase-free gradients, produced by denitridation of TiN-containing cemented carbides in vacuum atmospheres, or γ-phase-rich surface layers produced by nitridation of cubic carbide containing cemented carbides.

Special interest has been devoted to the effect of alternative binders (Fe-Ni-Co compositions) on the formation of gradients and their properties using nitrogen not only in the WC-TiC_TaC system but also in the Ti-Zr carbonitride system. Iron in the binder is beneficial for the formation of gradients, due to the higher activity of nitrogen in iron. The effect is highly dependent on composition and process conditions.

Computational thermodynamics has been successfully applied to model the kinetics of gradient formation in both Co-based cemented carbides. Good agreement between experiment and simulation regarding layer thickness, phase fraction distribution and element profiles was obtained on DICTRA modelling of gradient formation kinetics considering that all diffusion occurred in the liquid binder phase of a dispersed system model for example in Ni-based cemented carbides.

Nitridation of cemented carbides and cermets has once again been resurrected by various research schools in order to generate gradients that show superior wear properties in metal machining.

In the field of macro gradients, the Dual Property (DP) hardmetals for mining applications are one of the most well known cemented carbides since 1988 using macro-gradients. Controlled redistribution of the cobalt binder phase gives components which contain three distinct microstructural zones. These gradients, together with

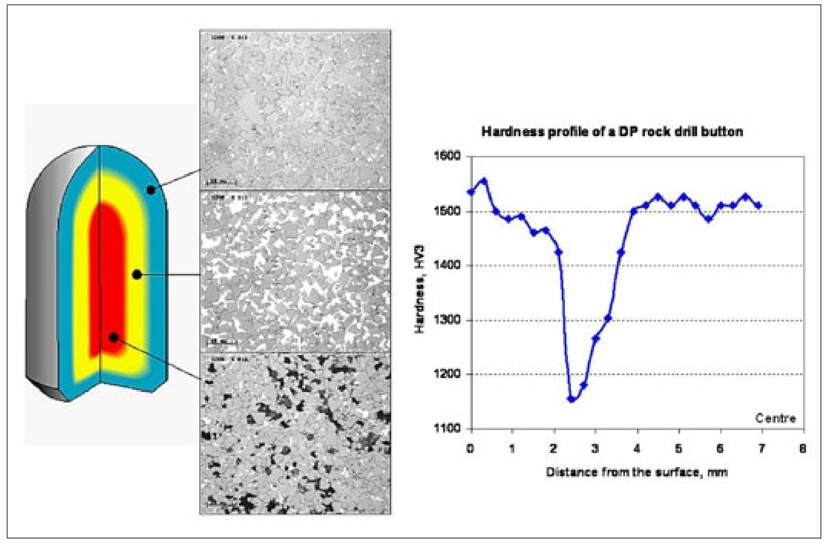

Fig. 5 The three distinct zones of the DP- carbide (Courtesy of T Hartzell, Sandvik Mining Rock Tools) [4]

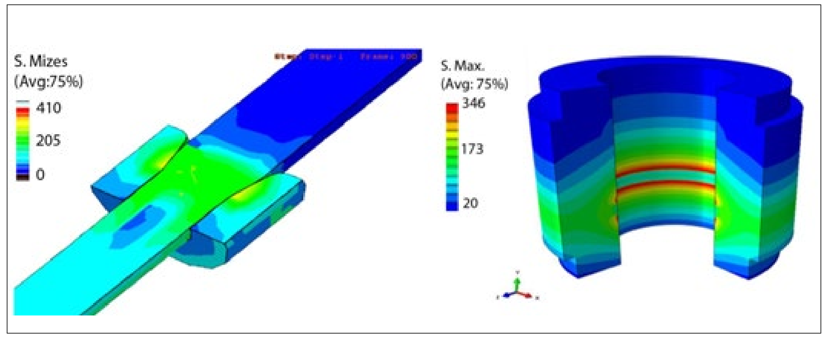

Fig. 6 Examples of FEM simulations for Sandvik products (a) Stress distribution in a stainless steel wire drawn through a hardmetal die (b) Image of the calculated stress distribution within a press-fitted hardmetal tool [4] (Courtesy Plansee)

their differences in thermal expansion, redistribute the internal stresses. It is, for example, possible to create a very hard and wear-resistant surface layer which is simultaneously pre-loaded with compressive stresses to prevent the initiation and propagation of cracks. Carbide having such a distribution of properties has high wear resistance at the surface combined with a tough underlying region. The initial application area was in rock drilling but today macro gradients are also used for tube and wire drawing tools and cold heading dies.

Modelling in manufacturing process and product application

Modelling has become a powerful tool in engineering and the hardmetal industry is no exception. Modelling of carbide production processes and applications are prevalent in the industry with reasonable success. But it is a challenge to develop suitable models to describe the behaviour of hardmetal since it is a composite consisting of metallic binder and hard refractory metal phases.

Continuing development of modelling methods is needed to simulate hardmetal pressing and sintering processes. One recent attempt is a multi-scaled or hierarchical model, which tries to integrate different dimensional orders of scale together. Intrinsic properties resulting from pressing could be considered as input to the modelling of sintering, such as initial inhomogeneity of microstructure, distribution of WC and pores, and localised residual stress in 'green body'. Other factors such as grain growth, phase change, heating cycle, should also ideally be included.

Modelling can shorten the new product development cycle, optimise parameters for field applications, and significantly reduce cost before going into mass production (Fig. 6).

In the design of hardmetal anvils for diamond synthesis for example, FEM can effectively assess stress distribution under different pressure, as well as changing dimensions and shape of the designed carbide component. Engineers also utilise FEM to simulate chip formation in the machining process, residual stress in micro-milling, wear mechanisms and the influence of cutting heat on tool life and to understand the plastic deformation and fracture of hardmetal, also under fatigue conditions. The development of measurement and experimental techniques is very much concurrent with modelling improvement.

Conclusion & outlook

In her closing remarks, Norgren stated, "A clear focus area for metal cutting and wear parts is fine grained hardmetals. In metal cutting, improved PVD techniques generating thin coatings on sharp cutting edges which benefit from fine grained cemented carbides, widens the application field for inserts and round tools. In solid endmills and drills, PVD coated fine grained cemented carbides are taking market share from traditional high speed steel cutting operations. With the increasing knowledge about interface structures, doping and properties this area will continue to grow. Combined with the increased research activity in alternative sintering processes such as, for example, field assisted sintering, spark plasma sintering and pulsed electric current sintering, the opportunity to go even finer in grain size on an industrial scale will be possible. Increased understanding of the physical phenomena governing WC grain growth and interfacial properties gained from combined atomistic and thermodynamic modelling together with microscopy studies will almost certainly result in further development of fine grain cemented carbides."

"In the future we will see an increased use of 3D techniques; for example the 3D atom probe and reconstructions of real 3D structures by combining Field Ion Beam (FIB) and EBSD techniques," Norgren added.

"High R&D activity in the field of alternative binders will continue. Fe-based alternative binders are used in some applications such as woodworking and special wear parts, more effort in alloy design, production and quality control is required to attain universality of application and production friendliness in a highly competitive market. Nevertheless, alternative binders are a future trend and will be even more important due to the new health legislations for Cobalt."

Norgren stated that "Modelling of manufacturing processes and product applications, will play an even more important role in carbide industry. It will cover a wide range of applications, from materials grade development, process optimisation, design automation, to product application and performance. Concluding the work being reviewed here, the future trends are: 1) Moving towards hierarchical modelling or multi-scales modelling at different scale, micro, meso, and macro, 2) Full product modelling from product design to processing and application, 3) Model validation, including materials characterization and measurement, and 4) Product performance monitoring."

Mechanisms of cobalt capping

The influence of carbon content on the bulk properties of Hardmetals is well known. However it is the surface of the hardmetal that plays an important role in determining the usability of hardmetals. The emergence of near net shape hardmetals which undergo none, or a minimum amount, of grinding before being pressed into use has resurrected the interest on the morphology of the as-sintered surface of hardmetals.

Until about perhaps a decade ago, the sintered skin of hardmetal had to be removed before use, since the as-sintered surface was neither well defined nor defect free. It was quite common to advise hardmetal product users to grind away about 0.2 mm of the surface to get full value for money. However, surface grinding is an expensive process and the first step to engineer the surface and reduce grinding is to study the as-sintered surface morphology.

On the other hand, to improve brazeability many mass produced hardmetal products have to be given an additional thin electrolytic coat of metallic nickel or cobalt. It has been quite a riddle to hardmetal manufacturers to see that some hardmetal parts had a skin of cobalt (cobalt- capping) on the as-sintered surface and others didn't. Cobalt capping leads to a layer of binder on the sintered surface and should not be confused with Co-enrichment, which causes surface near gradients of Co in the product.

Three papers [5- 7] at the 18th Plansee Seminar dealt with the phenomena of the evolution and possible mechanisms of cobalt capping.

Understanding cobalt layer formation: In situ observation and new insights on the mechanism

The research work presented by E Sachet and his colleagues [5] was fascinating, as for the first time it showed a real time experimental documentation of the appearance of cobalt on the surface of hardmetal samples during cooling. These authors studied primarily the influence of the cooling rate in the temperature range between 1360 to 1300°C for different alloys with different grain sizes (0.6 – 4 microns), grain growth inhibitors (Cr and Ta) and different surface carbon contents.

The sequence shown in Fig. 7 represents five steps, from a complete cobalt-free surface to a continuous cobalt layer, and demonstrates the characteristic morphologies of the cobalt layer formation observed for the materials used in this work.

The authors could clearly show that, depending on alloy composition, slow cooling promotes cobalt capping and it is easier to form a cobalt layer for alloys with a smaller grain size or a higher cobalt content under the vacuum sintering conditions used in this study. The process of cobalt capping is very rapid and occurs in a narrow temperature range, normally starting from the top of the sample and moving downwards by a nucleation and coalescence mechanism.

The authors explain the cobalt layer formation during cooling as a result of two interacting mechanisms. In between the solidification interval during cooling, binder phase can be transported either towards the surface (decarburising conditions) or towards the interior of the sample (carburising conditions). This is caused by different amounts of liquid binder as a result of the varying carbon content due to reactions with the sintering atmosphere or by temperature gradients inside the sample. After an initial transport of binder phase towards the surface, the layer formation is then driven by the surface tension of the cobalt and the layer forms as a result of optimisation of the surface/volume fraction of the binder on the surface.

The morphology of partially formed cobalt layers strongly support this mechanism as the different steps observed agree with the proposed model and confirm the strong influence of the cobalt's surface tension.

In situ observations provided additional data that support the formulated mechanism and add extra insight into the time scale and progress of the formation. Cobalt layer formation is indeed a fast process that happens within a time frame of 30-120 seconds and starts at numerous points on the sample surfaces. The duration and the starting temperature of the formation are dependent on the solidification

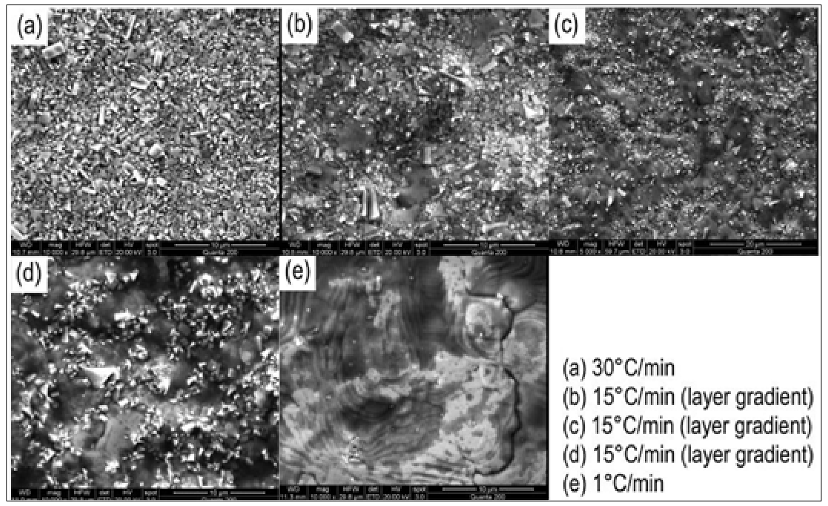

Fig. 7 The different stages of cobalt layer formation [5] (Courtesy Plansee)

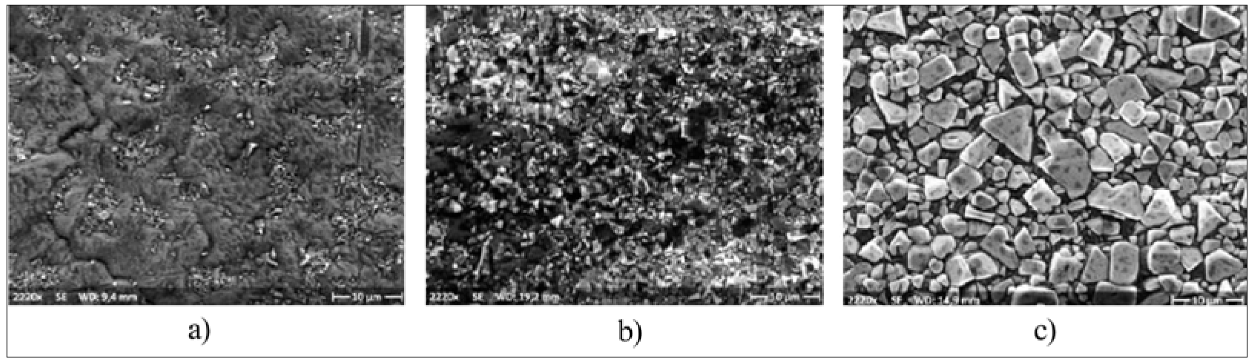

Fig. 8 Examples of different surface morphologies of sintered WC-10% Cobalt Hardmetals with different mean WC grain sizes: a) Fine grained Hardmetal with a cobalt film on the surface, the content being 76 Wt.%; b) Medium grained Hardmetal with islands of Cobalt films on the surface and a surface cobalt content of 18,7 Wt. %; c) Coarse grained Hardmetal with no surface cobalt film and a cobalt content of 14 Wt.% [6] (Courtesy Plansee)

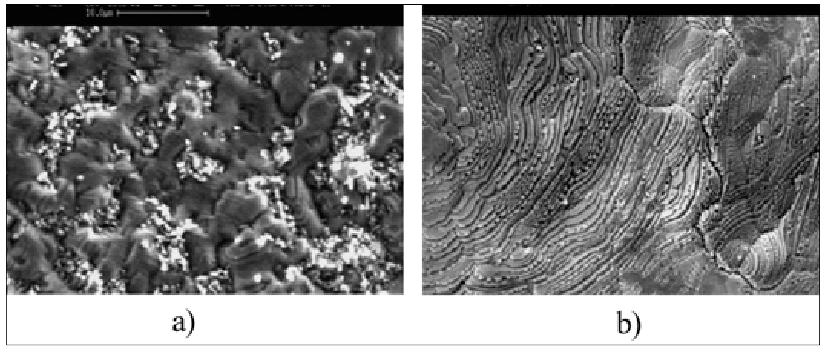

Fig. 9 Surface of fine grained WC-10% Co Hardmetal: a) fast cooling after sintering, the surface is coated with a discontinuous Co film . b) slow cooling after sintering, the surface is coated by a continuous Co film [6] (Courtesy Plansee)

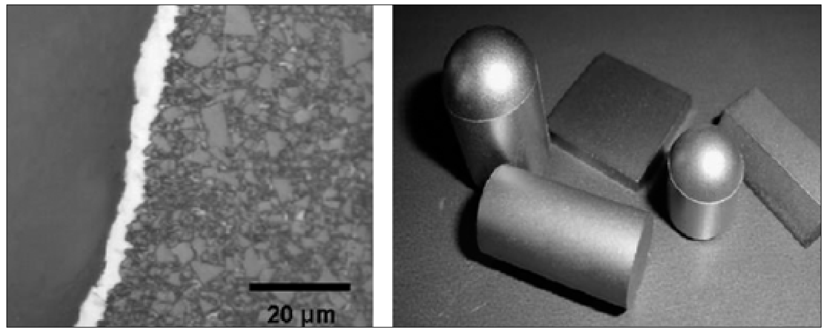

Fig. 10 Co Films on hardmetal products obtained by the Co capping technology [6] (Courtesy Plansee)

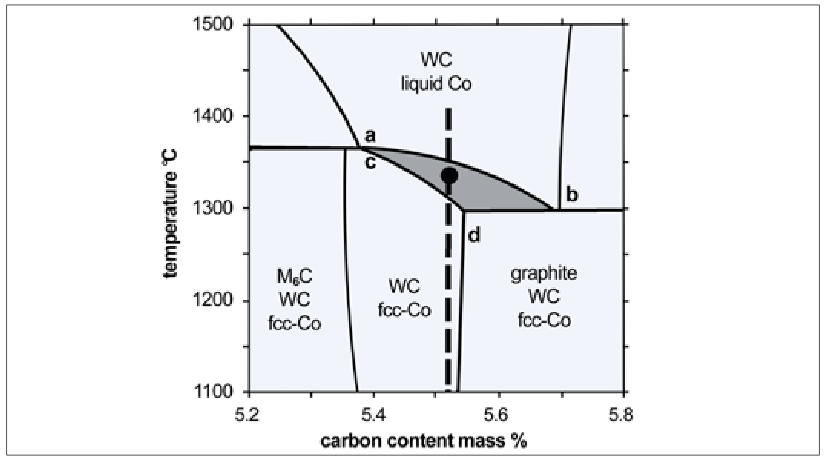

Fig. 11 Ternary phase diagram Co-W-C at 10 Wt.% Co [6] (Courtesy Plansee)

interval of the alloy used and thus by the composition and WC grain size.

This school of researchers postulate that the mechanism cannot be used to create thick surface layers of cobalt, as the transport of sufficient amounts of cobalt requires very slow cooling rates and would lead to the disintegration of the tungsten carbide skeleton. Faster binder transport is also not possible because the hardmetal microstructure will eventually be binder depleted and block further transport towards the surface. To prevent the formation of a cobalt layer, the process has to be either prevented by fast cooling within the solidification interval, or by applying mild carburising conditions upon cooling and therefore inhibiting binder transport towards the surface.

Cobalt Capping: A technique for improving the transverse rupture strength, fracture toughness and wettability by braze alloys of WC-Co hardmetals

The second paper on cobalt capping under industrial conditions for different carbide grain sizes and binder contents was presented by I Konyashin *et al.* [6] from Element 6. His explanation of the mechanism of cobalt capping is based on the action of capillary phenomena in thin channels between WC grains on liquid Co in the hardmetal near-surface layer.

The mechanism supposedly explains all the phenomena of the Co layer formation during sintering of various hardmetal grades followed by either fast or slow cooling. The authors report that a new technology for the fabrication of Co coated hardmetal articles has been developed on an industrial scale for hardmetal articles of different grades with continuous and defect-free Co coatings, with dramatic improvements of their as-sintered TRS, surface fracture toughness and wettability by braze alloys.

The technology is based on a stepwise cooling of hardmetal products after sintering in different temperature ranges at tailored rates. Fig. 10 shows the cobalt film on a hardmetal cross section and some products obtained with a shiny surface by using the cobalt capping technology.

As in the case of the previously mentioned paper by Sachet *et al.*, the underlining mechanism of cobalt capping is based on the knowledge of the ternary WC- Co phase diagram (Fig. 11).

Controlling cobalt capping in sintering process of cermets

The third paper on the topic is from S Englund and colleagues at Sandvik [7] who studied cobalt capping of cermets. In this work critical sintering parameters for the formation of cobalt capping on four different cermet grades were evaluated experimentally. The influence of the carbon activity, the sintering atmosphere (vacuum, flow rate, pressure, high pressure) and the cooling rate was investigated.

The results are in accordance with the known observations that the Co surface top-layer forms during a specific short temperature interval during the cooling step for each grade, but it is affected by the preceding conditions; e.g. enhanced by a preceding Co-enrichment in the surface zone in a decarburizing atmosphere.

The formation can be inhibited by using a carburizing atmosphere, such as carbon monoxide gas, or a sinter-HIP (Hot Isostatic Pressure) step during cooling. A phenomenological model for formation of Co-capping in cermets considering melting point of alloys, cobalt migration, carbon activities, vapor pressure of reactive elements as well as processing parameters (sintering atmosphere, cooling rate etc.) was presented.

The experimental results on Co-capping formation on cermet materials in this study are in general agreement with the observations carried out for WC-Co hardmetal materials in the literature. EPMA line-scans have shown a deeper depletion curve of cobalt when the CO (carburising gas) was removed at the early stages of the cooling step, indicating that the enrichment occurs as soon as the surface is decarburised. This effect is even stronger for vacuum conditions; but as observed, the actual Co-capping may be absent due to evaporisation of binder. Since the solidification temperatures and intervals depend on the cermet composition, (Table 2) different cermets show different cobalt capping characteristics (Fig. 12 and Fig. 13).

Fig. 12 shows that sintering in an argon atmosphere during cooling has led to a perfect cobalt capping for all cermet compositions. Fig. 10 shows the surface of the same cermet types sintered under a high carbon activity (CO pressure below 50 mbar). It is quite clear that the carbon

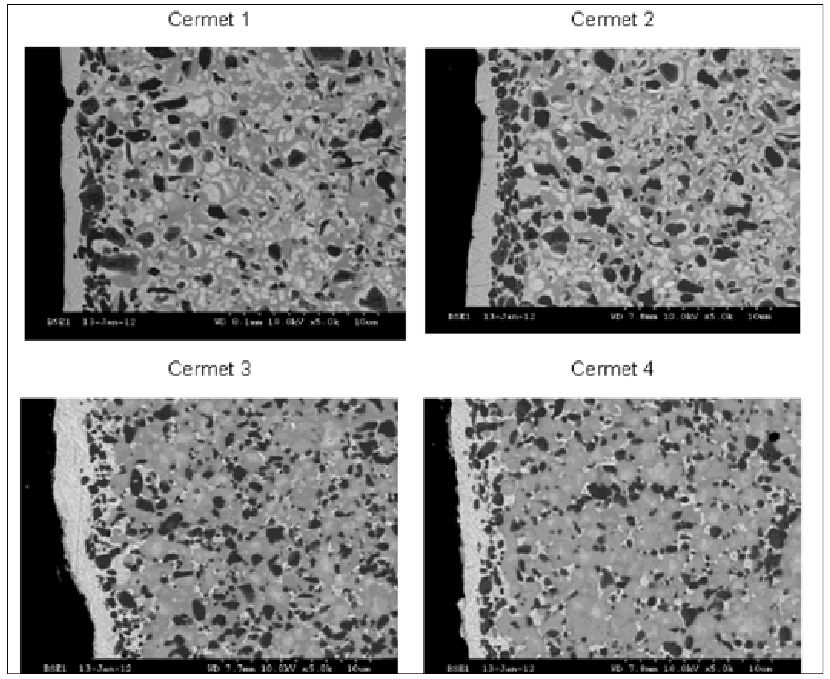

Fig. 12 SEM images of the top surface for different cermet alloys using an inert argon atmosphere [7] (Courtesy Plansee)

Sample	WC	Co	Ni	cc-phase*
CERMET 1	balance	11	5.5	67
CERMET 2	balance	11	5.5	67
CERMET 3	balance	14	-	67
CERMET 4	balance	18	-	67

* cc-phase is a carbonitride containing the metals Ta, Nb, W, Ti

Table 2 Chemical composition of the investigated cermets (Wt.%) [7] (Courtesy Plansee)

DSC-TG	CERMET 1	CERMET 2	CERMET 3	CERMET 4
Melting begin	1367 ±1	1382 ±1	1406 ±1	1405 ±1
Melting finish	1386 ±1	1411 ±1	1416 ±1	1416 ±1
ΔT	19 ±1	18 ±1	10 ±1	19 ±1
Solidification begin	1364 ±1	1396 ±1	1407 ±1	1411 ±1
Solidification finish	1331 ±1	1373 ±1	1391 ±1	1387 ±1
ΔT	33 ±1	22 ±1	16 ±1	24 ±1

Table 3 Melting and solidification temperatures of the investigated cermets [7] (Courtesy Plansee)

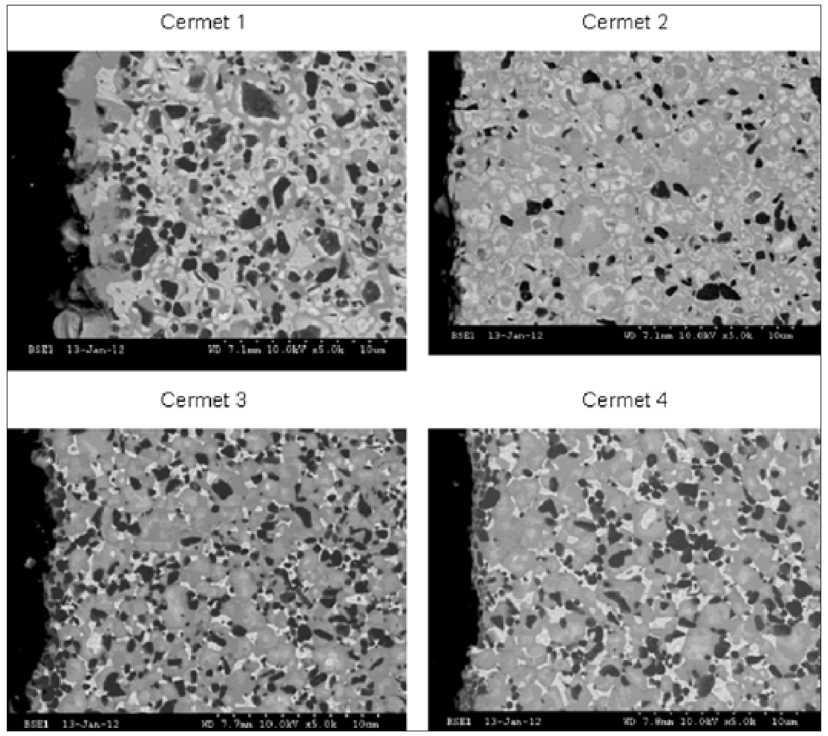

Fig. 13 SEM images of the top surface for all cermets sintered under a carburizing atmosphere (CO < 50 mbar) [7] (Courtesy Plansee)

activity has a significant impact on Co capping. Other published literature has also shown this relationship that a change in carbon balance results in changes on the surface solidification temperature and thus a non equilibrium condition between liquid and solid binder, leading to Co migration towards the interior of the samples under carburising conditions.

Conclusions

Conclusions and recommendations to control Co-capping formation in cermet grades have been summarised by the authors as follows:

- Based on these results, it can be concluded that the impact of cooling rate variations on Co-capping formation in cermets is less compared to the reported effects on WC-Co grades. Cooling rates below 5°C/min have a lower impact on Co-capping formation and a considerable effect on the final particle size in the microstructure.
- The Co-capping may occur during a specific temperature interval during solidification of the samples as reported in previous publications.
- Co-capping can be avoided by increasing the carbon activity in the surface of the cermets, i.e. by using a CO atmosphere during the cooling step avoiding Co-transport towards the surface and the formation of the binder-layer.
- Both a CO atmosphere and a HIP-treatment during cooling avoid Co-capping formation. However, it can not be stated if the CO-cooling and the HIP-cooling have different underlying mechanisms. For example the question if the high pressure mechanically pushes the binder phase towards the interior of the sample, or if the HIP results in an increase of the CO partial pressure due to release of impurities in the furnace still needs clarification. Regardless of the mechanism behind Co-capping, the furnace pressure and atmosphere are critical.
- If Co-capping is achieved during the sintering, it is still necessary to avoid binder evaporisation. Co evaporisation is fast at low furnace pressures (vacuum conditions) and at high temperatures. The results show that cermets grades with higher solidification temperatures and longer solidification intervals are more sensitive to evaporation if they are sintered in high vacuum atmospheres.

Finally the authors find it worth mentioning that the sintering furnace, the type of trays and location of the samples in the batch also affect the Co-capping formation. Since all the processes are sensitive to the partial pressure of the system, the Co-transport may be inhibited by conditions that increase the CO partial pressure locally. This phenomenon could also explain why the bottom surfaces of the samples often have much more surface Co than the other surfaces of the same samples when sintering at low pressures.

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Author

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PowderMet 2013: State of the North American Powder Metallurgy industry

The PowderMet 2013 International Conference on Powder Metallurgy and Particulate Materials was held in Chicago, USA, from June 24-27. Organised by the Metal Powder Industries Federation (MPIF), the event attracted over 800 participants and included three days of presentations and a trade exhibition. A keynote presentation by MPIF President Matthew Bulger gave delegates a detailed overview of the current state of the North American Powder Metallurgy industry.

In his opening address at PowderMet 2013, MPIF President Matthew Bulger (NetShape Technologies, Inc.) stated that most metal powder producers, equipment makers and PM parts companies, especially fabricators of Metal Injection Moulded (MIM) parts, had reported increases in sales during 2012. The industry, he reported, had regained its growth momentum and 2013 is expected to offer a repeat of last year's modest but positive gains.

Bulger reported that total 2012 metal powder shipments increased by 9.6% to an estimated 507,643 short tons (Fig. 2). Iron powder shipments in 2012 rose 5.5% to 383,984 short tons, representing the third consecutive year of steady growth. Of this total the PM parts share grew by almost 6% to 343,777 short tons (Fig. 3).

North American shipments of copper/copper-base and tin powders for PM applications actually declined last year by 4.7% to 16,209 short tons, stated Bulger (Fig. 4).

Of the other materials, tungsten and tungsten carbide powders registered minor declines, while stainless steel, molybdenum, and nickel powders experienced modest gains. Recent new information on aluminium powder shows a substantially larger market than previously reported at some 80,000 short tons.

According to MPIF statistics, the market for MIM powders grew 35.5% in 2012 to 1,971,580 pounds (895 mt). However, because these statistics do not include all powder makers, observers put the market higher at approximately 2-3 million pounds, added Bulger (Fig. 5).

PM process equipment makers, especially compacting press builders, highlighted an upward trend by part makers to increase their manufacturing capacity for PM parts. Press

Fig. 1 Matthew Bulger stated that most metal powder producers, equipment makers and PM parts companies had reported increases in sales during 2012 (Courtesy MPIF)

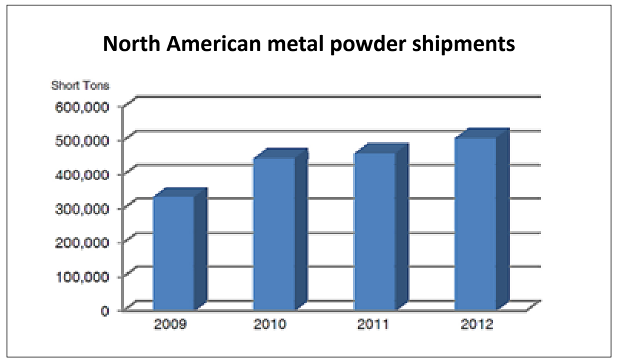


Fig. 2 North American metal powder shipments 2009 - 2012 (Copyright MPIF)

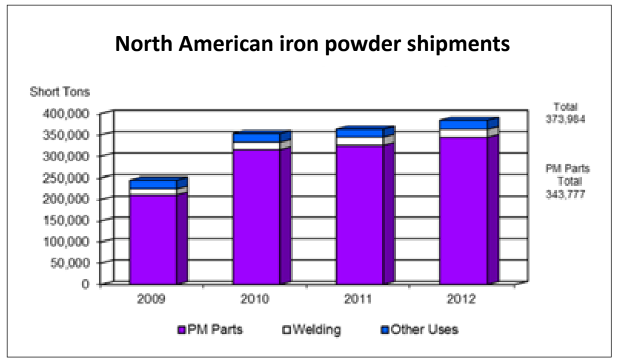


Fig. 3 North American iron powder shipments 2009 - 2012 (Copyright MPIF)

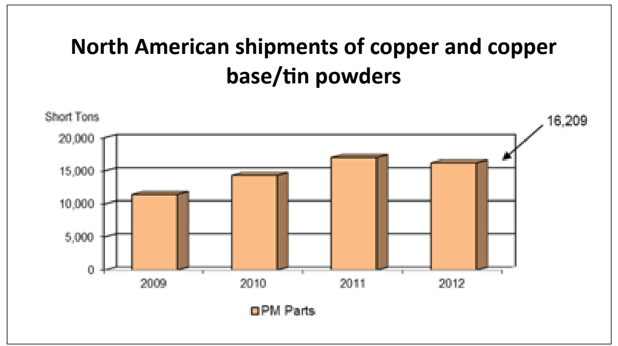


Fig. 4 North American copper and copper base/tin powder shipments 2009 - 2012 (Copyright MPIF)

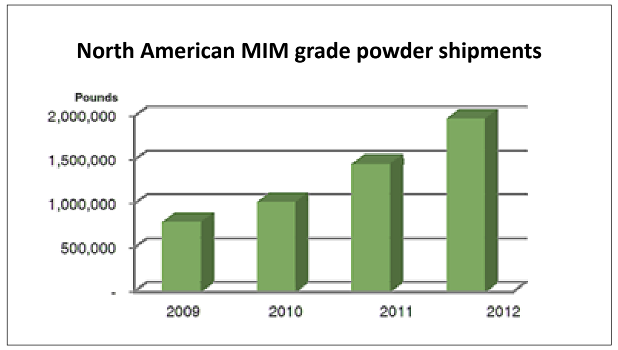


Fig. 5 North American MIM grade powder shipments 2009 - 2012 (Copyright MPIF)

sales registered very strong gains last year compared with 2011, and the industry ended 2012 with a backlog of more than $19 million, reported the MPIF's Powder Metallurgy Equipment Association.

"PM parts makers serving the automotive market fared very well last year, while those serving the industrial market and products related to home building experienced more modest growth," added Bulger.

MIM companies recorded a solid year of increased sales in 2012. The hot isostatic pressing (HIP) industry enjoyed another outstanding year as well, based on casting densification and the processing of MIM parts to full density.

2013 outlook for North America

Turning to current conditions, Bulger said that even in the face of robust auto sales, a recovering US manufacturing base, and a rebound in new home construction, PM executives still forecast only modest growth because consumers remain wary about the US economy.

Iron powder shipments through the first four months have increased 6.7% to 136,535 short tons. Copper-powder producers are cautiously upbeat, stated Bulger, forecasting annualised growth in the 3 - 6% range.

Equipment makers anticipate increased business levels based on capacity expansions among PM parts fabricators, especially the addition of presses in the 100 to 500 ton range.

Bulger reported that larger multi plant PM parts makers, especially auto-parts suppliers, are adding new capacity to meet growing demand. Some medium and smaller size family owned businesses, who supply the broader industrial marketplace, are signalling a mixed outlook.

The MIM industry continues to thrive with annual North American sales estimated at $250 -$300 million. Firearms applications remain the leading MIM parts market followed by medical/dental, general industrial products, automotive, and electronics. As far as the automotive market is concerned, there are applications where MIM technology is indispensable, in components for electric and hybrid vehicles and in new turbo-charged gasoline engines.

The Hot Isostatic Pressing (HIP) outlook signals another good year that should continue well into the future, commented Bulger. Although casting densification dominates HIP usage, representing about 70% of the market, PM applications are also growing for MIM part densification, tool steels, and oil- and gas-exploration projects.

Weakening demand characterises the tungsten market outlook along with softer raw materials prices. Both the carbide and tungsten alloy shipments were down during the first quarter, particularly tungsten carbide products in mining and construction industries. Defence applications are also down, heavily impacted by the government's sequestration program. However, oil and gas drilling applications are doing well, and aerospace applications are on an upward trend.

PM automotive trends

"This year could see North American light vehicle production rising well above 15 million units. However, the really big increases should hit the market in 2015-16 when many new models with new engines and transmissions are introduced," stated Bulger. "This trend includes more four and six cylinder engines, turbochargers, and six, seven, and eight speed transmissions. The use of variable valve timing (VVT) systems will continue to grow in order to help OEMs meet 2016 CAFE standards," he added.

It is estimated that the PM parts content in the typical US made car, can be as high as 1,000 individual parts representing 325 applications, and will increase slightly to 44.5 pounds (20.2 kg) this year. This compares with 44 pounds (20 kg) in 2012, which had increased two pounds from the previous year. In contrast, the PM content in the typical European built car remained even last year at 19.4 pounds (8.8 kg), while the PM content in the typical Japanese car declined slightly to 20 pounds (9.1 kg). Both countries experienced a decline in vehicle production, added Bulger.

Powder Forged (PF) connecting rods remain one of PM's stellar successes, dating back to its first use in North America in a Ford 1.9 litre engine. About 60% of North American auto engines use PF rods currently. Worldwide, it is estimated that more than 850 million PF rods have been produced since 1987, with no major failures reported.

Technology developments

"Metal powder producers continue to invest in programmes to improve PM materials and expand PM parts applications," stated Bulger. "For example, one company is developing a new high density lubricant binder that provides higher single pressed densities via warm compaction. A competitor is working on developing new lubricants with improved hygroscopy resistance and ejection. Another company has a new line of stainless steels that improves machinability two to three times over standard stainless grades."

"Compacting press builders are designing enhanced high tonnage CNC hydraulic presses and higher speed designs," continued Bulger. "Several firms are focused on supplying PM parts for an innovative stationary fuel system that converts natural gas to oxygen and hydrogen to produce electric energy."

Additionally, researchers are studying powder based composites for defence and energy applications. Potential uses include aluminium alloys for lighter-weight marine and armoured vehicles, iron based soft magnetic composites for motors, compressors, and power conversion, and nanomaterials for nuclear energy, solar, and space applications.

Addressing the topic of Additive Manufacturing (AM), Bulger noted that laser-sintering 3-D printers show promise sintering metals for complex aircraft parts.

A bright future

"Investing in applied and fundamental research is vital to our industry's future," stated Bulger. "Technology breakthroughs may take years before true commercial applications, but we must never neglect researching new ideas and funding them. In the context of the worldwide metals and materials fields, PM may be a blip on their radar screens. But on the other hand, many industries would grind to a sudden stop without our vital technology."

"PM was heralded as a twentieth century technology based on superstar products, and it will gain new status as a global technology in the twenty-first century. That is, if we encourage that insatiable curiosity to conceive new ideas, maintain the entrepreneurial spirit of the pioneers who launched the PM industry, and cooperate through joint development programs world-wide," concluded Bulger.

The PowderMet 2013 exhibition

PM industry professionals recognised at PowderMet

2013 Fellows

APMI International, a professional society for the PM industry, welcomed both Dr Olle Grinder, Consultant, PM Technology AB, and Roger Lawcock, Director, Product & Process Development, Stackpole International, to the 2013 Class of Fellows. They received the award at a special luncheon held during PowderMet 2013.

Dr Grinder is a world renowned powder metallurgist who has actively contributed to the advancement of PM technology in Europe, Asia and North America. A member of APMI for over 27 years and possessing over 43 years of PM experience, Dr Grinder has published 60 reports in international journals or conference proceedings.

Dr Grinder has made unparalleled contribution in fully dense PM technology, and is one of the leading experts on the subject of Hot Isostatic Pressing (HIP). A recipient of a PhD in metallurgy and material science from the Royal Institute of Technology, Sweden, in 1977, he has made significant contributions in the sintering of high alloys, including tool steels, stainless steels, and cemented carbides. He is author/co-author of four patents, two of which directly related to PM, and has been a lecturer at the Royal Institute of Technology for over 25 years.

Lawcock is one of the pioneers

Dr Olle Grinder (left) and Roger Lawcock receive the 2013 APMI Fellow Award

of the roll-densification process for gears, converting numerous gears from wrought to PM. A member of APMI for nearly 20 years, Lawcock has promoted the advancement of PM as a science by disseminating and exchanging information through his many publication efforts. He received the MPIF Howard I Sanderow Outstanding Technical Paper Award as the outstanding technical paper at the 2005 annual conference, as well as the SAE Arch T Colwell Award for significant contribution to literature.

Lawcock received his MSc in metallurgy from the University of Manchester, UK, in 1987. In over 30 years in PM, Lawcock has focused on high volume, high performance automotive applications based on lean alloys, high temperature sintering and improvements to core and surface density. He has been instrumental during the material and design development phases of several award winning components.

Established in 1998, the Fellow Award recognizes APMI members for their significant contributions to the society and high level of expertise in the technology of Powder Metallurgy, practice, or business of the PM industry. Fellows are elected through their professional, technical and scientific achievements.

Distinguished Service Awards

The MPIF also announced recipients of its Distinguished Service to Powder Metallurgy Award.

Established in 1968, the award recognises North American individuals who have worked a minimum of 25 years in the PM industry and whose long term contributions and achievements deserve special recognition. This year's recipients are:

- Susan M Abkowitz, COO and Vice President of Technology, Dynamet Technology, Inc.
- Robert T Beimel, President, JIT Tool & Die, Inc.
- Russell A Chernenkoff, Senior Research & Development Engineer, Metaldyne LLC
- Mark S Greenfield, Vice President, Global Material Science, Kennametal Inc.
- Paul A Hauck, Director, Engineering, Marketing & Sales, Kinetics Climax, Inc.,
- Roger Lawcock, FAPMI, Director Product & Process Development, Stackpole International, Automotive Gear Division
- Gilles L'Espérance, FAPMI, Professor, Materials Engineering, École Polytechnique de Montréal
- Michael E Lutheran, President, Royal Metal Powders Inc.
- Nicholas T Mares, Vice President of Marketing, Asbury Graphite Mills, Inc.,
- James J Oakes, Vice President, ATI Tungsten Materials, Metalworking Products
- Richard Pfingstler, CEO, Atlas Pressed Metals
- Joseph T. Strauss, President, HJE Company, Inc.

Winners of the 2013 MPIF Distinguished Service Awards. Left to right: Joseph T Strauss, Richard Pfingstler, James J Oakes, Nicholas T Mares, Michael E Lutheran, Gilles L'Espérance, Susan M Abkowitz, Robert T Beimel, Russell A Chernenkoff, Mark S Greenfield, Paul A Hauck and Roger Lawcock (Courtesy MPIF)

PowderMet 2013: Continuing technical developments offer growth for the Powder Metallurgy industry

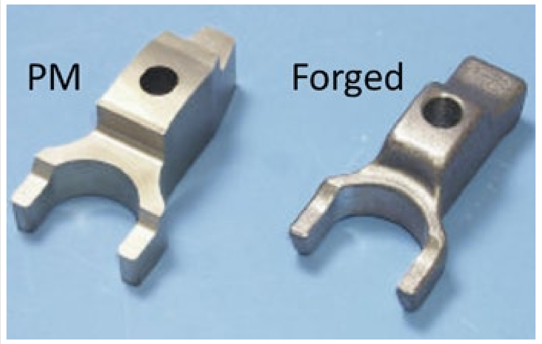
The Special Interest Program at PowderMet 2013, held in Chicago, June 24-27, 2013, proved to be an excellent opportunity to showcase the advances in Powder Metallurgy. In the session "Technologies for PM Growth" authors identified material and process developments that offer improved properties, allowing PM to compete against existing technologies and provide opportunities for growth. Dr David Whittaker reports exclusively for *Powder Metallurgy Review* on a number of key presentations.

From raw material to new challenging applications

The Special Interest Program on Technologies for PM Growth began with a series of presentations from the major powder suppliers, highlighting the material and process developments that they had introduced with a view to opening up new higher-performance application opportunities for the ferrous PM structural parts sector.

The opening presentation in this session came from Ulf Engstrom, (Höganäs AB, Sweden) on behalf of his co-authors, Caroline Larsson, Sigurd Berg and Christophe Szabo.

It is recognised that green issues are becoming an increasingly important factor in determining the relative merits of competing materials and technologies. The benefits of PM, as compared with wrought steel processing routes in terms of reduced energy consumption and higher material utilisation in the component forming process itself, are well documented. However, the comparisons provided at the opening of this presentation were considerably more rigorous than this in that they involved full life cycle analyses, beginning with mining/extraction of raw materials and ending with end-of-life recycling of components.



Material	Weight of final component, g	Material utilisation, %	Processing
Steel technology			
SS2225 (25CrMo4)	194	68	Cut from bar, Forging, Machining, Heat treatment
PM technology			
Astaloy CrM+0.3C	196	97	Compaction, Sinter hardening
D. AE+0.5C	196	97	Compaction, Sintering, Heat treatment

Fig. 1 The component selected for the life cycle analysis case study and the relevant material and processing data [1] (Courtesy MPIF)

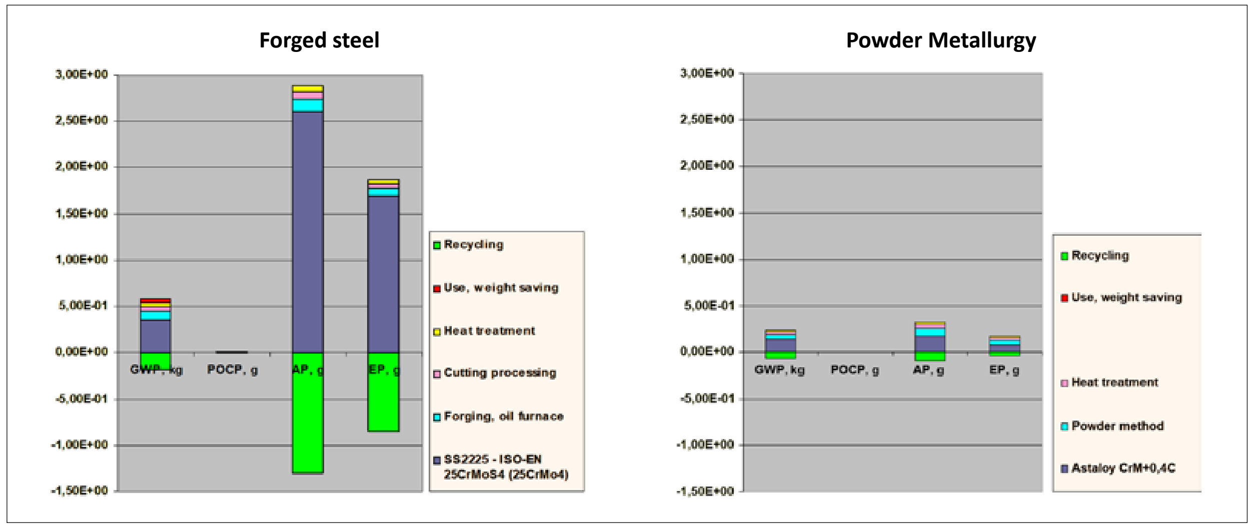


Fig. 2 Life cycle analyses showing the superiority of PM over steel processing in terms of environmental impact [1] (Courtesy MPIF)

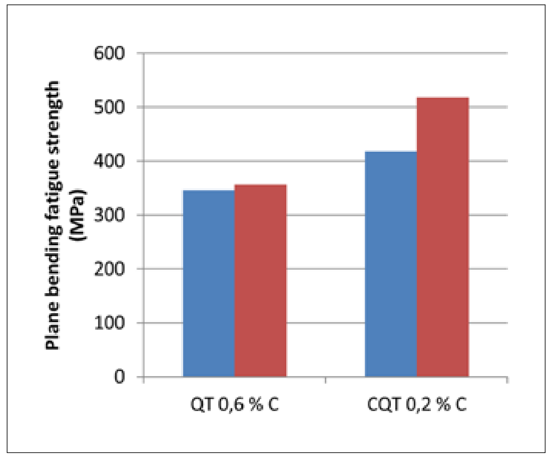


Fig. 3 Plane bend fatigue strengths of Distaloy AQ in the through-hardened (left) and case-hardened (right) conditions [1] (Courtesy MPIF)

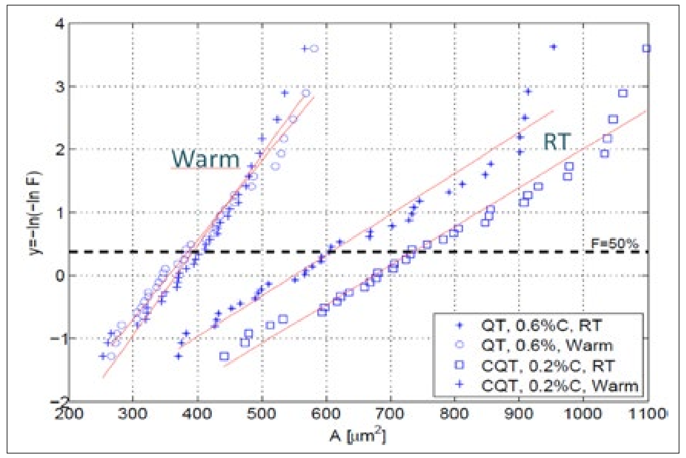


Fig. 4 Comparison of pore sizes and probability of occurrence in Distaloy AQ products produced by warm compaction and room temperature compaction [1] (Courtesy MPIF)

Environmental impact factors

These analyses considered the environmental impact factors:

- Global Warming Potential (CO_2, CH_4) - GWP
- Photochemical Ozone Creation Potential - POCP
- Acidification Potential (SO_2, NO_x) - AP
- Eutrophication Potential (NO_x, PO_4) - EP

As a case study, production routes for an injection yoke by wrought steel processing and by PM, using two different PM materials (Astaloy CrM + 0.3%C and Distaloy AE + 0.5%C), were assessed (Fig. 1).

Firstly, the presented results of these analyses showed the very significant advantage of PM over the wrought steel route in relation to the environmental impact factors (Fig. 2).

Secondly, the comparisons of the two PM material types showed the environmental credentials of using the chromium-containing Astaloy CrM material as compared with the 4% Ni Distaloy AE. Although the move away from PM materials highly alloyed with Ni is partially motivated by cost considerations, these green issues are also of increasing importance in material selection and Cr- and leaner Ni-alloyed grades offer the opportunity to fulfil these requirements, stated the authors.

The leaner Ni-alloyed material highlighted was Hoganas AB's Distaloy AQ, containing diffusion-alloyed additions of 0.5%Ni and 0.5%Mo. This material can achieve density levels over 7.3 g/cm³ when warm compacted and can achieve very high levels of dynamic properties in the heat treated condition, particularly after case hardening.

Fig. 3 shows the levels of plane bend fatigue strength attainable in the case-hardened and through-hardened conditions at room temperature compaction and warm compaction density levels. The benefits of warm compaction in relation to fatigue strength are related to the reduction in both the size and frequency of occurrence of large pores in the sintered structure (Fig. 4).

The highlighted Cr-alloyed materials were the fully pre-alloyed grades, Astaloy CrA (1.8% Cr) and Astaloy CrM (3% Cr, 0.5%Mo). In the assessments presented, Astaloy CrA was used as a base for the elemental addition of either 1% Cu or 2% Ni. Warm compaction of the material with the 2% Ni addition showed that a density level of around 7.25 g/cm³ could be attained compared with around 7.1 g/cm³ for room temperature compaction.

These materials are well suited to processing by sinter-hardening and Fig. 5 shows that, on sinter-hardening with a carbon gradient, the Astaloy CrA + 2% Ni material can achieve fatigue and tensile strength levels comparable to much more highly alloyed heat treated materials and unique combinations of fatigue strength and elongation, even at room temperature compaction density levels.

Outlook

The presentation concluded with some predictions as to how these material and process developments can enhance PM's capability for addressing growth opportunities in challenging product applications. Fig. 6 provides some views as to how the highlighted materials might fit into a number of important existing and potential product niches, including the industry's "holy grail" of transmission gears.

Finally, the promise was discussed of future developments of "low pressure processing", involving vacuum sintering and gas quenching, that might provide further enhancements in the properties of the highlighted Cr-alloyed grades and how these processes might be combined with state-of-the-art hard finishing operations to provide an optimised PM gear production route.

New lubricant system facilitates higher density PM parts

Francis Hanejko (Hoeganaes Corporation, USA) gave an update, on behalf of his co-author Shelton Clisby, on the development of a new lubricant system, which, in combination with

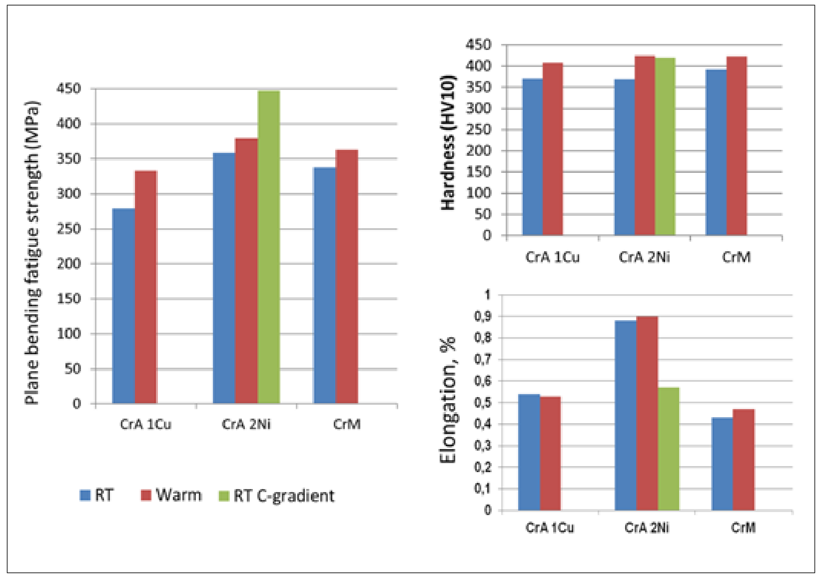


Fig. 5 Fatigue and mechanical properties of sinter-hardened materials, based on Astaloy-CrA or Astaloy CrM [1] (Courtesy MPIF)

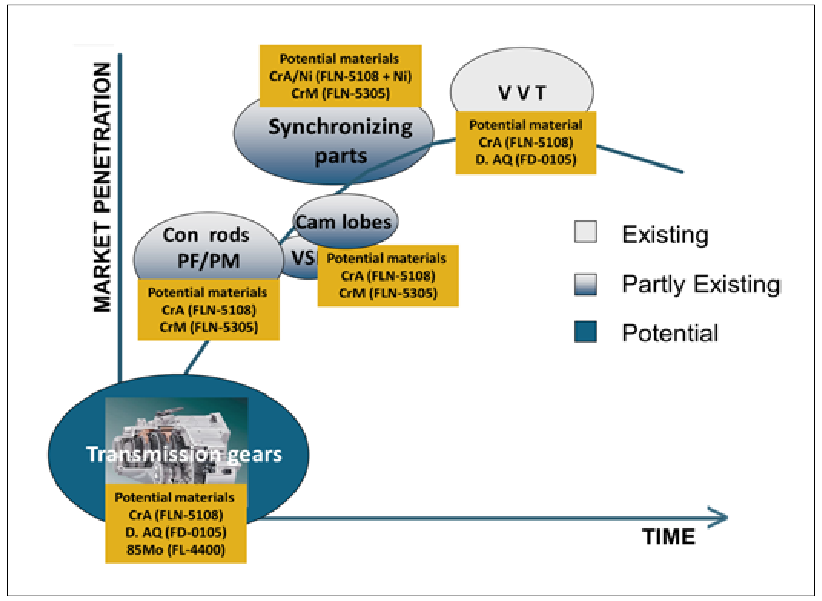


Fig. 6 Challenging growth areas for PM and potential materials [1] (Courtesy MPIF)

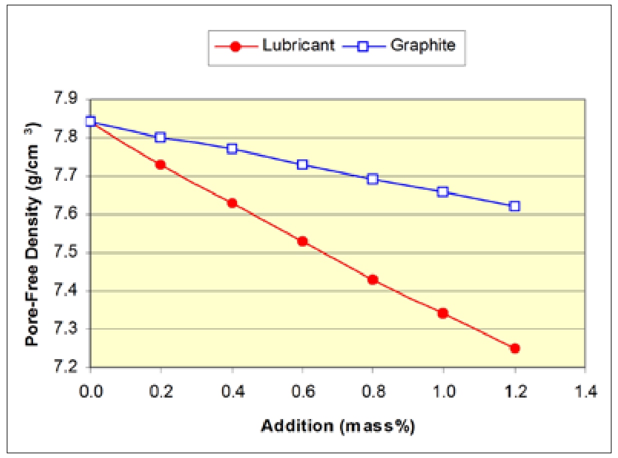


Fig. 7 Effect of lubricant and graphite additions on Pore Free Density (PFD) [2] (Courtesy MPIF)

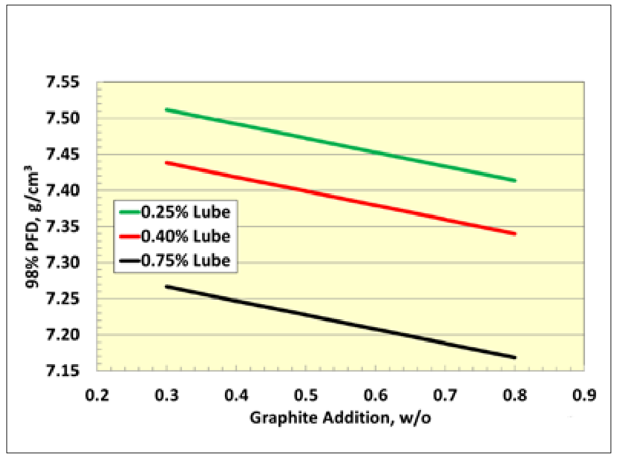


Fig. 8 Effect of lubricant and graphite levels on maximum green density [2] (Courtesy MPIF)

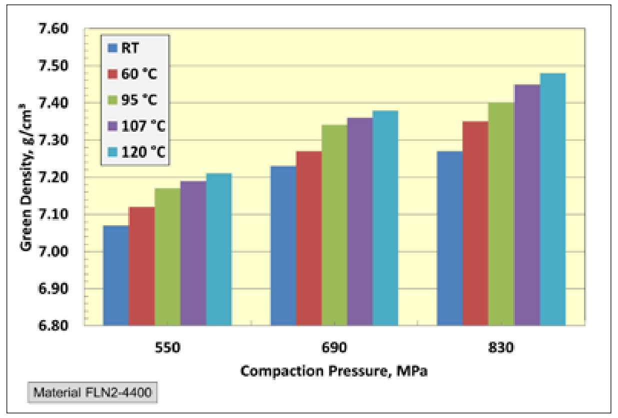


Fig. 9 Effect of compaction temperature and pressure on green density [2] (Courtesy MPIF)

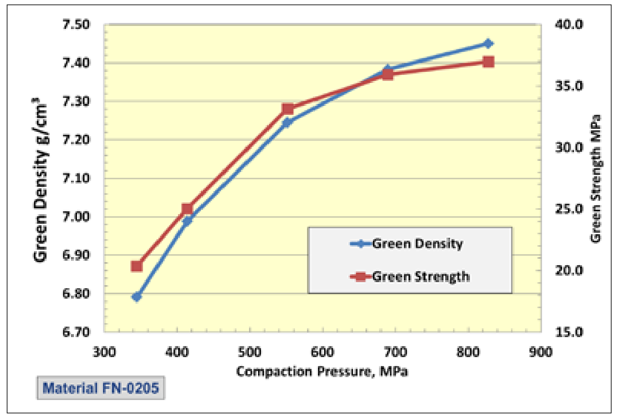


Fig. 10 Compressibility and green strength (Material FN-0205) [2] (Courtesy MPIF)

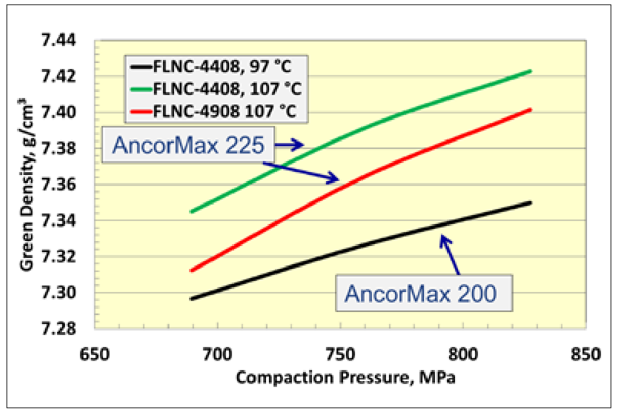


Fig. 11 Compressibility of FLNC-4408 and FLNC-4908 [2] (Courtesy MPIF)

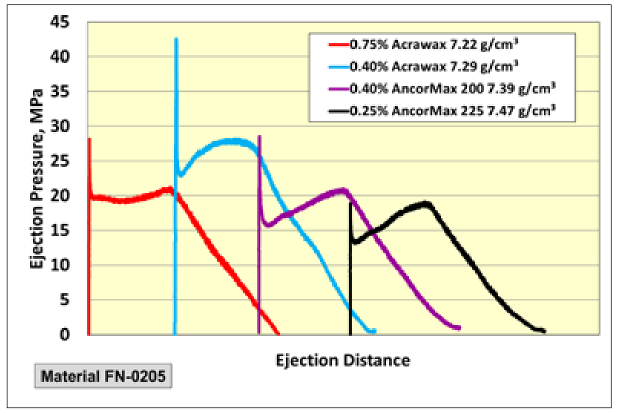


Fig. 12 Comparison of ejection characteristics (for compaction at 830 MPa) [2] (Courtesy MPIF)

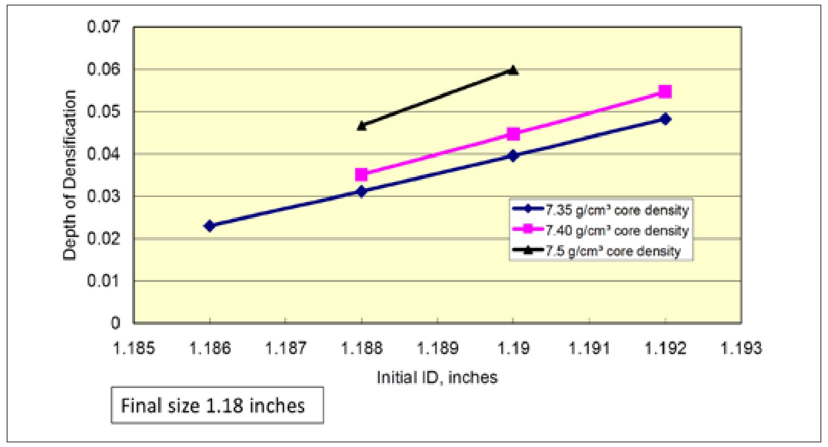


Fig. 13 Effect of core density on depth of densification in surface cold rolling of PM gears [3] (Courtesy MPIF)

high-pressure warm die compaction, was capable of enhancing the density of PM structural part materials to a level approaching 7.5 g/cm³.

New lubricant system

In a presentation last year at PowderMet 2012 it was reported that this lubricant was still in the development phase and was referred to only as a "new lubricant system". The lubricant system has now been given the trade name AncorMax 225, will be launched commercially during the third quarter of 2013 and considerably more detail was given on its attributes in this presentation.

The basis for this lubricant system development was the recognition that maximum achievable green density is dependent on the parameter Pore Free Density (PFD), defined as the density of a green compact if all of the porosity could be removed, and that the low-density additions of lubricant and graphite have a particularly negative impact on PFD (Fig. 7).

It was noted that the practical limit of green density is around 98% of PFD as, beyond this limit, micro-laminations can be formed during compaction. The means of approaching this limit with AncorMax 225 were:

- To use the lubricant at as low an addition level as 0.25 wt%.
- To utilise warm die compaction and an increased compaction pressure to increase material compressibility.

AncorMax 225 is used in an ANCORBOND premix (i.e. the lubricant is also operating as a binder for alloying additions), containing 0.25 wt% total lubricant with an optimum part ejection temperature of ~107°C (225°F), hence the "225" designation.

It has been demonstrated that maximum green density can approach

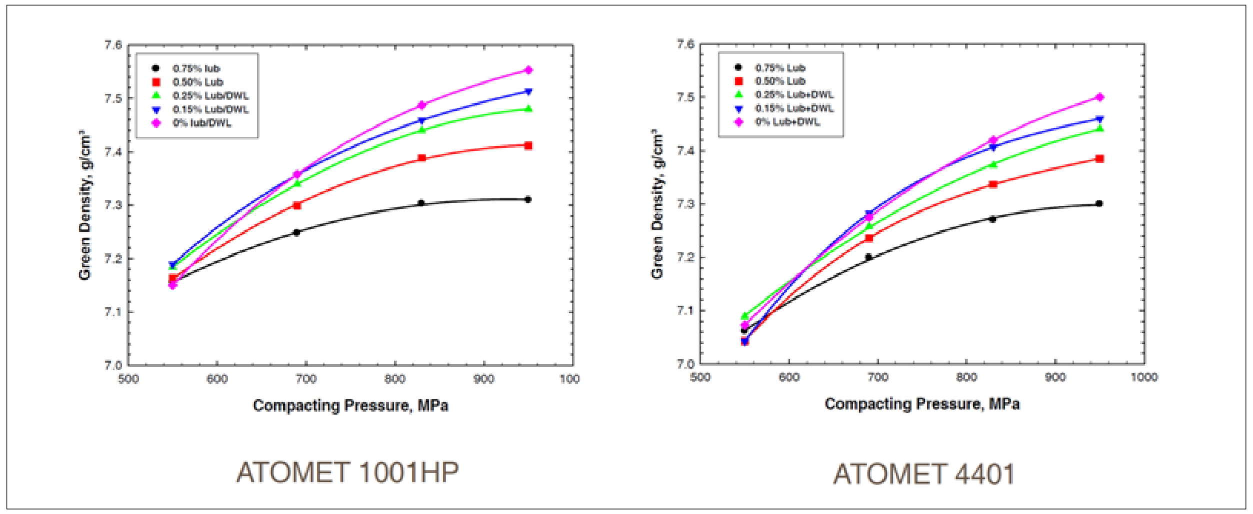


Fig. 14 Influence of lubricant content on achievable green density over a range of (cold) compaction pressures [4] (Courtesy MPIF)

7.5 g/cm³, depending on alloy and graphite content and compaction pressure as demonstrated in Figs. 8 and 9. Using a compaction pressure of 830 MPa, a room temperature green strength of around 35 MPa can be achieved (Fig. 10). Green strength at the warm compaction temperature was assessed as being around 20 MPa.

An ability was demonstrated to achieve a density of 7.4 g/cm³ with FLNC-4408 sinter-hardening material (Fig. 11). It was also shown that ejection characteristics with AncorMax 225 at 0.25 wt% were equivalent to those with 0.75 wt% Acrawax (EBS), see Fig. 12.

Set against these advantages, a few part geometry limitations of this approach were referred to:

- Limitations in part height are anticipated. Parts over 25 mm in height may not be practical. This limitation could be overcome by increasing lubricant level, but this would be at some sacrifice in green density.
- Larger parts may not be practical, because of short die contact time and inefficient thermal transfer.
- The relatively high compaction pressures, required for optimum compaction, of >550 MPa may not be practical for parts that need thin or fragile punches in the forming tooling.

However, for applications within these geometrical constraints, encouraging prototyping trials have been carried out.

The presentation was concluded with the revelation that, in such a prototyping trial on a batch of ~2,000 parts, a weight control of +/- 0.3% was achieved, with no degradation in surface finish of parts being observed.

In a separate presentation entitled "Advanced High-Performance Gear Processing via PM" later in the Special Interest Program, Francis Hanejko underlined the importance of achieving high "core" density in PM gear products that were to be subject to surface densification. Data was presented on the effect of core density of a PM gear on the achievable depth of densification (Fig. 13). It was concluded that a core density of >7.35 g/cm³ is desirable. The use of the AncorMax 225 lubricant system may therefore be a key contributor to achieving this condition.

Methods of achieving high density in PM structural parts

Francois Chagnon (Rio Tinto Metal Powders, Canada), on behalf of his co-authors, Sylvain St. Laurent (Rio Tinto Metal Powders) and Yannig Thomas (Industrial Materials Institute) gave the company's views on processing variants aimed at increasing the density of ferrous PM parts and the influence of materials issues in these processes.

The process variants covered were:

- Higher pressure cold compaction
- Warm die compaction
- Densification through sintering shrinkage

Studies on the effect of lubricant content on compressibility in

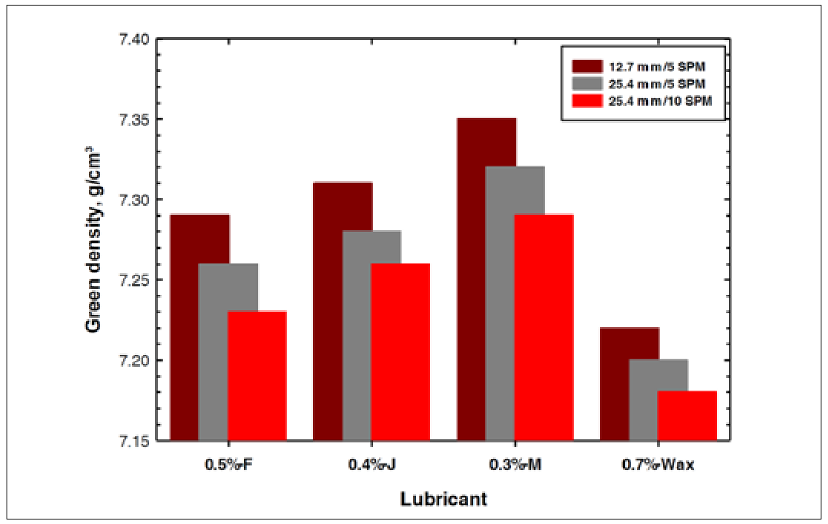


Fig. 15 Effects of lubricant content and compaction stroke rate on green density [4] (Courtesy MPIF)

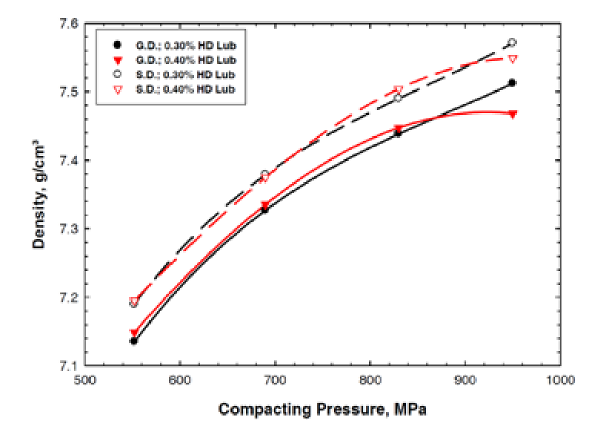


Fig. 16 Increase of density during sintering [4] (Courtesy MPIF)

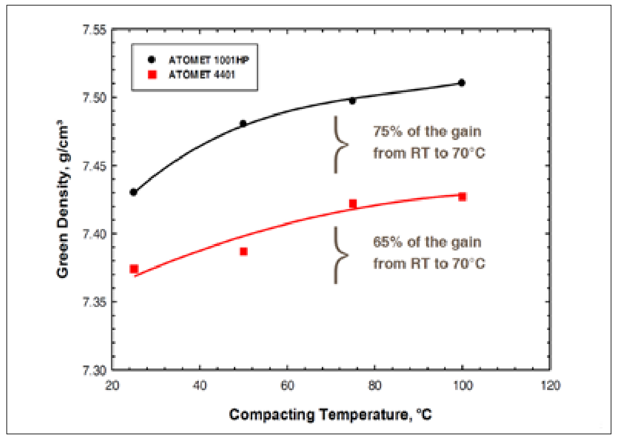


Fig. 17 Increase of green density with compaction temperature [4] (Courtesy MPIF)

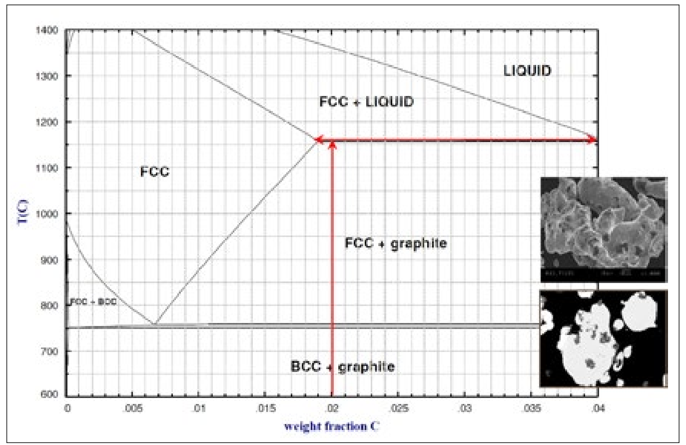


Fig. 18 Super Solidus Liquid Phase Sintering [4] (Courtesy MPIF)

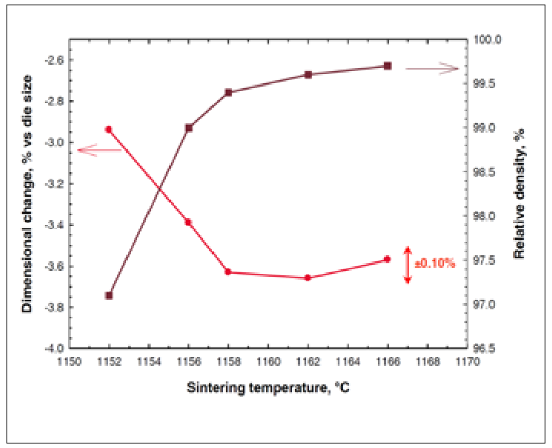


Fig. 19 Densification and dimensional change control in sintering of malleablised iron [4] (Courtesy MPIF)

cold compaction have led to the conclusions that:

- At low compaction pressure, e.g. 550 MPa, powder compressibility plays an important role in controlling maximum achievable density, while the effect of lubricant content is marginal (Fig. 14)
- At 950 MPa compaction pressure, where the 98% of pore-free density limit is being approached, lubricant content becomes the most important factor limiting achievable green density while the effect of powder compressibility becomes more marginal (Fig. 14)
- The development of new polymeric lubricants with improved lubrication efficiency makes it possible to reduce their contents in powder mixes, therefore increasing pore-free density and achieving higher green densities with good ejection behaviour.
- Green density decreases with the height of the part and with compaction rate (Fig. 15)

In subsequent sintering, it was observed that the gain in density between the green and sintered states increased with compaction pressure (Fig. 16), indicating that a loss of density due to larger springback at higher compaction pressures is recovered during sintering.

Powder temperature

The effect of powder temperature in Warm and Warm Die Compaction is, in part, related to the effect of temperature on the yield strength of plain iron. It was shown that 65-75% of the potential density gain can be achieved when compaction temperature is raised to as low a value as 70°C (Fig. 17).

Sintering densification

The influence of sintering densification was considered in the context of the Super Solidus Liquid Sintering mechanism (Fig. 18) and included the concept of malleabilisation of high carbon iron powder as presented at the 2012 World Congress (see *Powder Metallurgy Review* Vol. 2 No. 1 pp49).

Using this approach, full density PM materials can be produced with dimensional change tolerances of +/- 0.1%, when parts are properly sintered in the sintering temperature window (Fig. 19). Green density is the most important parameter to control in order to maintain good sintered dimensional tolerances.

Tensile strength of 770 MPa, yield strength of 520 MPa and an elongation value of 2.5% and axial fatigue strength of 275 MPa can be achieved with a pearlitic microstructure, using this sintering technology, the author stated.

High-density technology for future PM growth

A presentation by Rajesh Parameswaran (PMG Indiana Corporation, USA), on behalf of his co-authors, Salvator Nigarura and Michael Bird, provided the company's view on the potential for higher performance applications to be unlocked by the use of higher density process options,

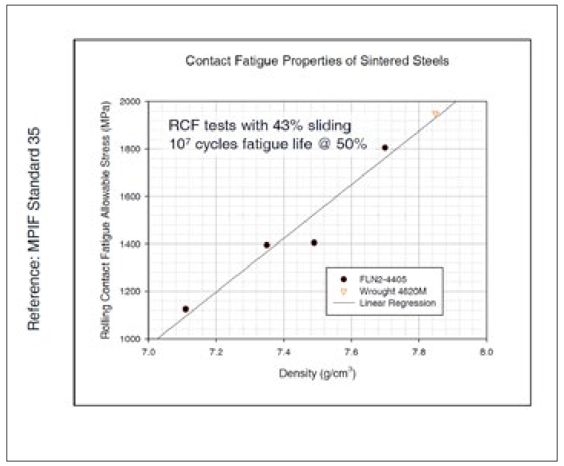


Fig. 20 Contact fatigue strength of sintered steels [5] (Courtesy MPIF)

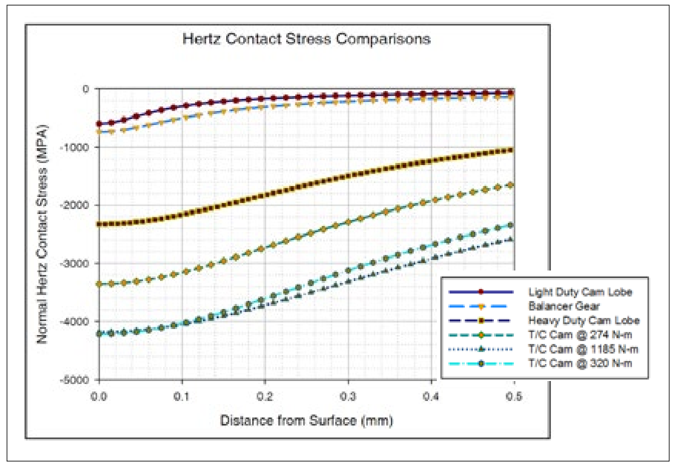


Fig. 21 Contact stress requirements for a range of cam applications [5] (Courtesy MPIF)

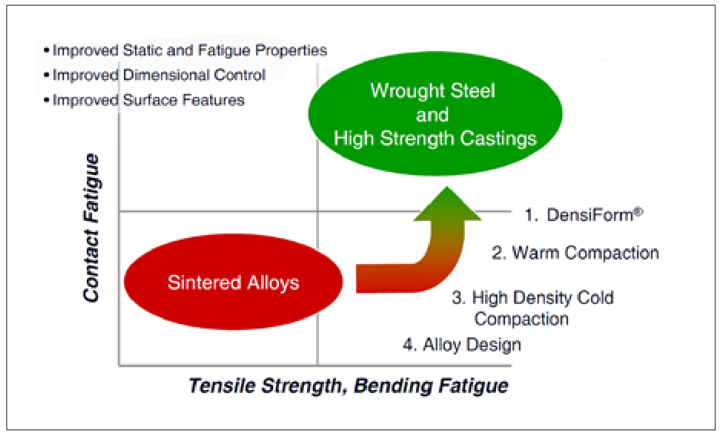


Fig. 22 Effects of various technologies in enhancing properties [5] (Courtesy MPIF)

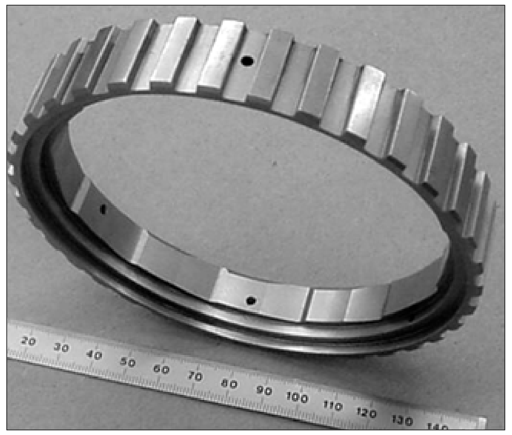


Fig. 23 Roller one-way clutch race [5] (Courtesy MPIF)

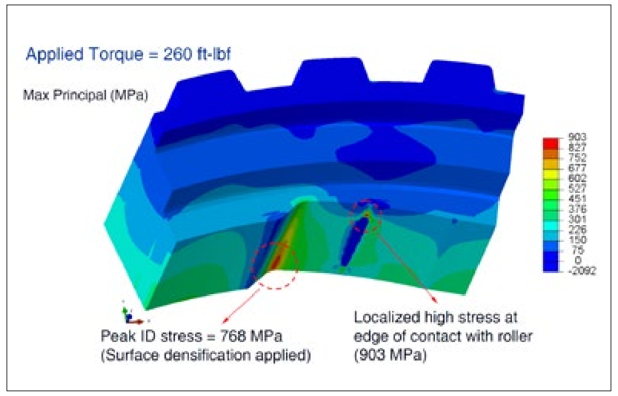


Fig. 24 Stress distribution in roller one-way clutch race [5] (Courtesy MPIF)

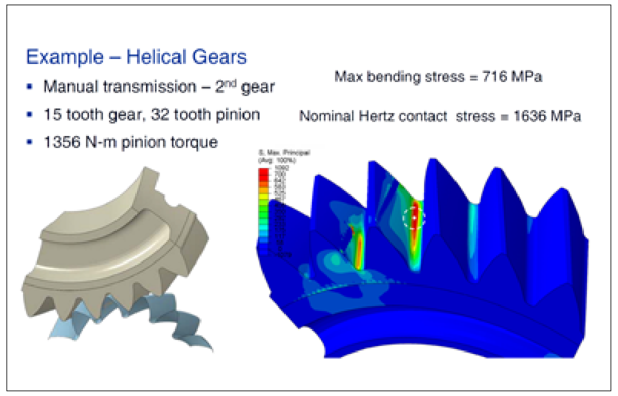


Fig. 25 2nd speed manual transmission gear [5] (Courtesy MPIF)

with particular reference to automatic transmission clutch race and manual transmission gear applications.

Conventional press and sinter

The presentation began with a review of the capabilities of conventional press/sinter PM processing in relation to applications, density levels and mechanical properties. Mechanical properties were shown to clearly depend on density; trend lines for contact fatigue and bending fatigue for conventional PM materials could be used to predict mechanical properties for fully dense wrought steel. This review culminated in the conclusion that the maximum achievable contact fatigue strength (a property key to the target higher performance applications) is around 1400 MPa at typical press densities of 7.3 g/cm³ (Fig. 20).

Comparison of this value with the contact fatigue requirements of a range of applications (one-way clutch races, light and heavy duty cam lobes) lead to the conclusion that conventionally processed PM materials cannot satisfy the requirements for torque convertor outer race cams (Fig. 21).

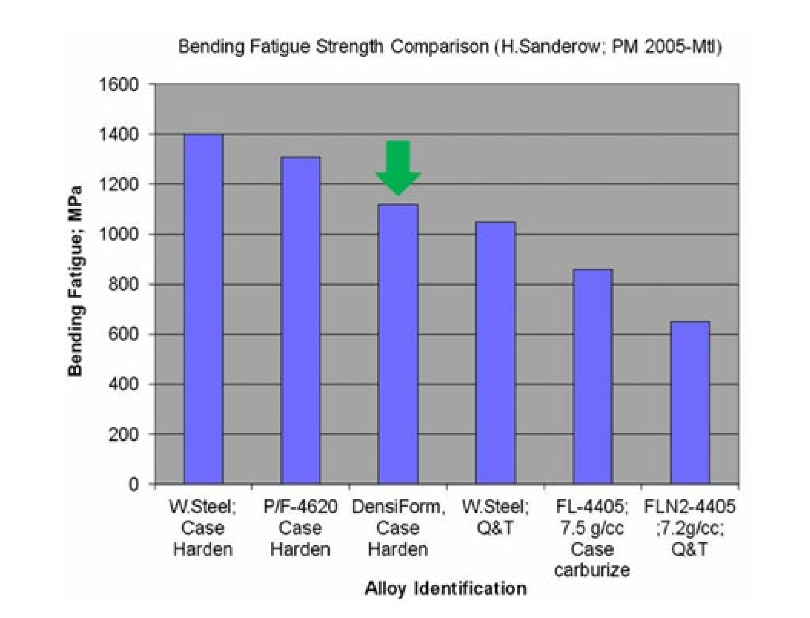


Fig. 26 Competitive position of DensiForm® in enhancing bending fatigue strength [5] (Courtesy MPIF)

An emphasis on surface densification
A need for densification was therefore defined and, based on the recognition that the stress fields in the targeted applications are highly localised in the surface layers of the component, the emphasis was on surface densification methods, in particular the company's proprietary DensiForm® technology. Fig. 22 shows schematically the effect of DensiForm® technology on bending fatigue and contact fatigue strength, as compared with bulk densification PM technologies and in the context of wrought steel performance levels.

Growth opportunities
Growth opportunities were highlighted in components such as:

- Torque convertor races for automatic transmissions
- Lower speed gears for manual transmissions.

Torque converter races in particular call for:

- Contact stress >2500 MPa
- Maximum tensile stress >700 MPa
- Von Mises >1800 MPa.

In the example cited of an outer race for a torque convertor roller one-way clutch (Fig. 23), rollers lock-up against cam and race under torque with high stress (hoop and contact) at full torque (Fig. 24). Surface densification can be effective with this type of application as maximum principal stress and normal contact stress fall by 54% and 77% respectively over the first 1 mm from the surface. In relation to the "core" strength requirements, it was concluded that higher core density is a key to success with highly loaded applications.

Turning to manual transmission gear applications, the example was considered of a 2nd speed helical gear (Fig. 25). The nature of the stress field for this type of component requires high strength near the surface and moderate strength in the core. It was concluded that the key to success here is surface densification with moderate core density.

The influence of DensiForm® on bending fatigue strength is summarised in Fig. 26 in comparison with PM materials with a range of bulk densities, including fully dense Powder Forged material, and with wrought steel. In the case-hardened condition, DensiForm® delivers a bending fatigue strength somewhat lower than Powder Forging or a wrought steel route, but, at >1000 MPa, the level achieved is substantially higher than the maximum bending stress experienced by the 2nd speed gear.

For higher speed manual transmission gears, it was again concluded that surface densification with a higher core density may be the key to attacking this market.

Powder forging demonstrates superiority in the connecting rod competition

An extremely up-beat presentation on the superiority of the Powder Forging route was provided by Edmond Ilia (Metaldyne LLC, USA) on behalf of his co-authors Kevin T Tutton and George Lanni.

Practically ever since the emergence of Powder Forging as a viable means of manufacturing automotive connecting rods some 35 years ago, there has been continuing debate on its merits relative to the main competing technology of open die drop forging.

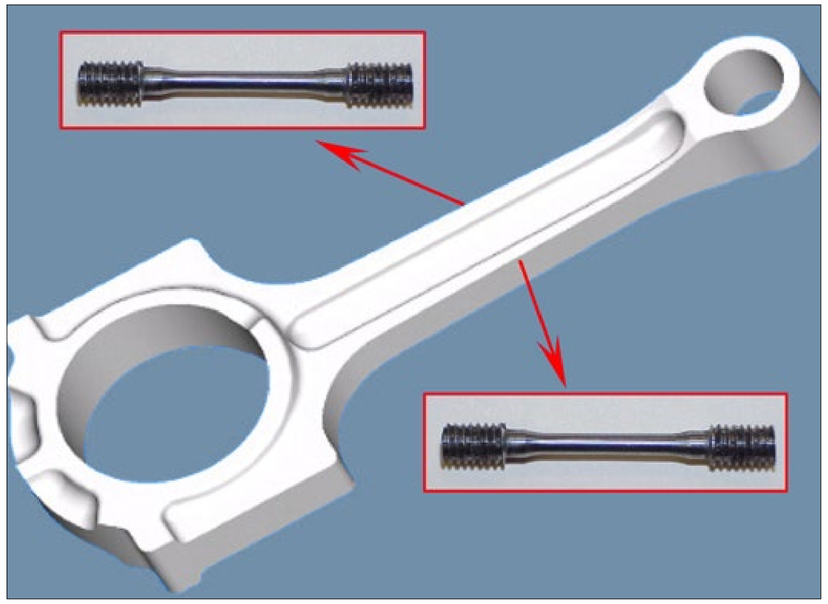


Fig. 27 Cylindrical specimens machined from the I-beam of PF connecting rods manufactured with HS170M [6] (Courtesy MPIF)

In the presentation by Ilia the comparison of the two competitive process routes was set in the context of their relative responses to the increasing demand from automotive OEMs for higher strength connecting rod materials in order to enable the light-weighting of rods or the use of a given size of rod in a higher performance engine.

Evaluation of mechanical properties
Ilia first described the range of higher strength material grades that have emerged from the Powder Forging (PF) industry's response to this challenge. These have included:

- New optimised grades introduced by Metaldyne themselves, with copper contents ranging from 3 to 3.5% (HS150M, HS160M and HS170M), that have higher and more consistent mechanical properties than the previous standard 2%Cu material
- Materials developed by GKN that use a base iron powder pre-alloyed with 3% copper to homogenise the strengthening effect of the copper. Additional copper can be introduced into this base material, as desired, through an elemental addition
- A material, introduced by Sinteron in collaboration with Höganäs AB, that is based on the pre-alloyed Astaloy CrL grade.

The Drop Forging (DF) industry's initial material development was aimed at offering higher strength and at attacking PF's perceived competitive advantage of big-end cap fracture splittability, explained Ilia. This material, a modified C70 (AISI 1070) grade, raised carbon content from the previous norm of 0.4-0.5% to 0.7%. The effects of this carbon content increase were to increase strength, to confer fracture splittability, but to sacrifice some machinability.

More recent developments in DF connecting rod materials have been aimed at further strength enhancements, retention of fracture splittability and, in some cases, attacking the machinability limitation. These grades have included:

- 36MnVS4, a material with lower carbon content to aid machinability and with a micro-alloying addition of vanadium and increased molybdenum content to increase strength
- Other vanadium micro-alloyed grades, 46MnVS6mod (0.46%C, 0.63%Si, 1.02%Mn, 0.26%Cr, 0.20%Ni, 0.13%V and 70MnVS-4high (0.70%C,0.20%Si, 0.83%Mn, 0.15%Cr, 0.14%Ni, 0.19%V)
- A material, developed by Hyundai, in which the carbon content in C70S6 was reduced and the silicon content was increased. Vanadium was also added to this grade to increase strength.

The tensile properties of several of these high strength PF and DF grades were measured on test-pieces taken from the I-beam sections of forged connecting rods as shown in Fig. 27.

The results of these tensile tests are shown in Table 1 and Fig. 28. As can be seen from these results, these high strength grades were mainly quite comparable with one another in terms of tensile properties.

	UTS (MPa)	YS (MPa)	Elongation (%)	Area Reduction (%)
HS170M	1,209	864	10%	19%
3-PA [9]	1152	877	9%	N/A
Sinteron CRL	970	746	10%	17%
HPF110 (Development)	1158	840	6%	N/A
S1-FC [11]	1091	843	12%	N/A
46MnVS6mod [12]	1157	849	10%	32%
70MnVS4high [12]	1217	823	9%	19%

Table 1 Comparative tensile properties of selected high strength PF and DF grades [6] (Courtesy MPIF)

Material	Stress ratio r	Cycles	FS at 50% SR (MPa)	FS at 90% SR (MPa)	FS at 10% SR (MPa)	Scatter Material (MPa)	Ts	Number of Tests
C70	-1	10M	326	252	400	58	1.59	20
C70	-2	10M	345	283	406	48	1.43	20
C70	-1	10M	288	252	323	28	1.28	25
36MnVS4	-2	10M	353	258	448	74	1.73	15
36MnVS4	-1	10M	358	337	372	11	1.10	16
36MnVS4	-1	10M	328	308	347	15	1.13	15
36MnVS4	-1	10M	370	339	402	25	1.19	20
36MnVS4	-2.5	10M	460	431	489	23	1.14	20
36MnVS4	-2.5	5M	412	402	422	8	1.05	20
70MnVS4	-2.5	5M	427	337	518	71	1.54	18

Table 2 Published fatigue data for DF con-rods [6] (Courtesy MPIF)

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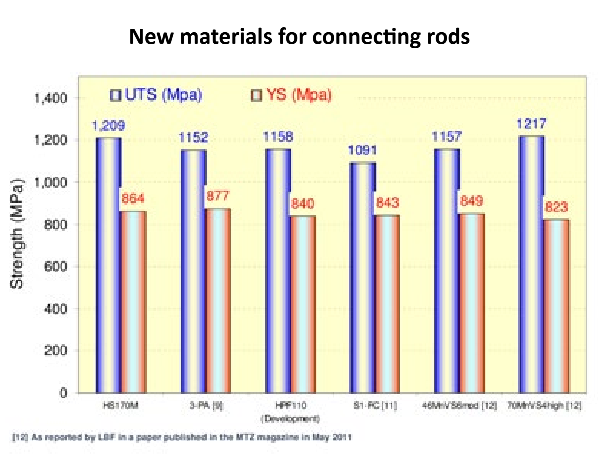
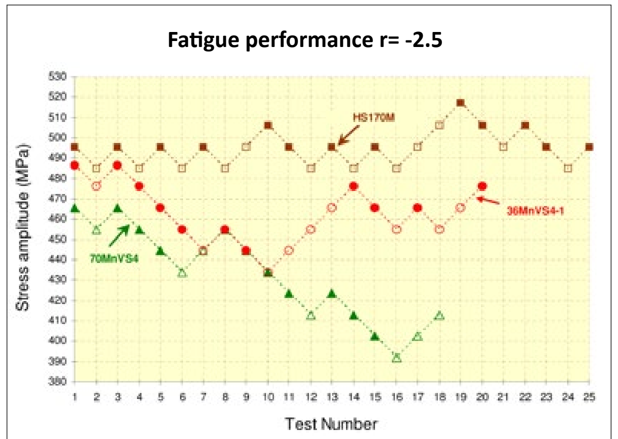
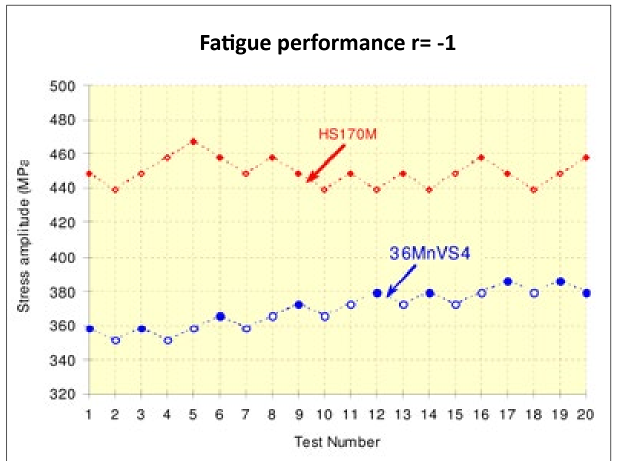


Fig. 28 Tensile properties for high strength con-rod materials [6] (Courtesy MPIF)



MPa	Fatigue Strength at 50% SR	Fatigue Strength at 90% SR	Scatter
36MnVS4-1*	460	431	23
70MnVS4 *	427	337	71
HS170M	494	485	8

Fig. 29 Comparative axial fatigue performance of DF and PF grades at R = -2.5 [6] (Courtesy MPIF)



MPa	Fatigue Strength at 50% SR	Fatigue Strength at 90% SR	Scatter
36MnVS4	370	339	25
HS170M	451	441	8

Fig. 30 Comparative axial fatigue performance of DF and PF con-rod grades at R = -1 [6] (Courtesy MPIF)

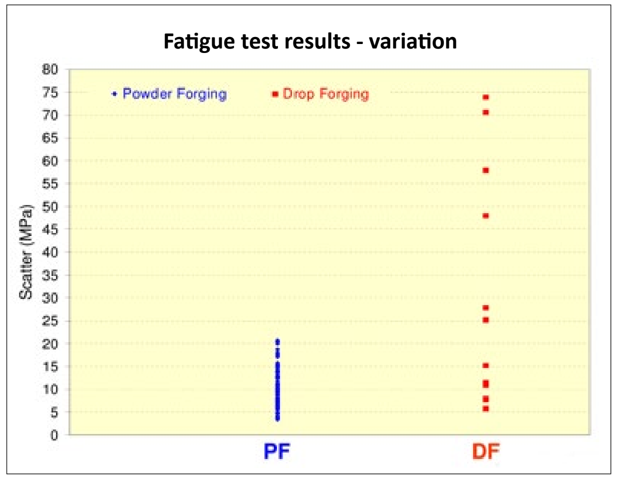


Fig. 31 Comparison of fatigue strength scatter for PF and DF con-rods [6] (Courtesy MPIF)

Fatigue performance of connecting rods

Ilia stated that a much more interesting comparison emerged in terms of axial fatigue properties, which is a more relevant comparison as fatigue is the critical criterion in designing connecting rods.

In these tests the fatigue strengths of the DF grades 36MnVS4 and 70MnVS4 were compared with the PF grade, HS170M.

Ilia stated that the results of tests conducted using the staircase method, as defined in MPIF Standard 56, and at a stress ratio, R, of -2.5, demonstrate the superiority of HS170M in terms both of the fatigue strength at 90% probability of survival and of the scatter in results (Fig. 29). The 90% probability of survival value is the most commonly used parameter in connecting rod design and the degree of scatter controls the level of safety factor that must be applied to the resulting design.

The superiority in fatigue performance of HS170M over that of 36MnVS4, in terms of both strength at 90% probability of survival and of degree of scatter, was even more marked in fully reversed (R= -1) tests, as demonstrated in Fig. 30.

The observed high level of scatter in fatigue performance is quite typical of reported data on drop forged connecting rods, stated Ilia (Table 2). The comparative variations in fatigue test results, reported for PF and DF rods are shown graphically in Fig. 31.

The low level of scatter and, hence, of required safety factor, gives the PF grades a significant edge in terms of the capability for light-weighting in design, he said.

Scanning electron microscopy studies of fracture faces after fatigue testing revealed the underlying reason for the high scatter in strength of DF rods, stated Ilia. These studies revealed the presence of forging defects, particularly along the trim line, such as oxides, folds and micro-cracks (Fig. 32), which can act as crack initiators.

Design advantages

A further source of potential weight reduction in PF rods was revealed in discussing issues related to "design for the process." For instance, because

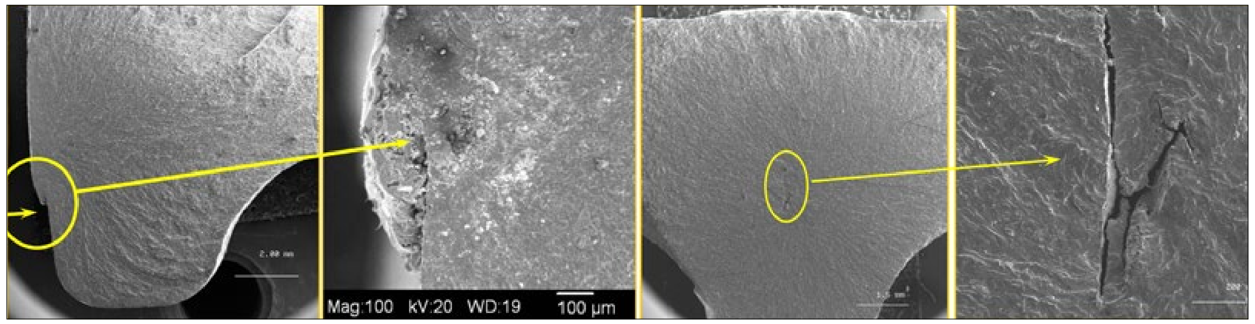


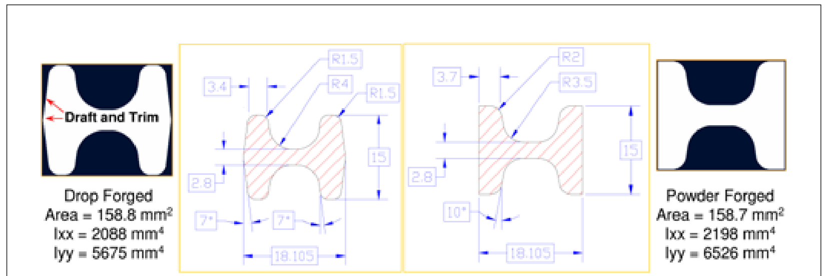
Fig. 32 Manufacturing defects observed in DF con-rods [6] (Courtesy MPIF)

there is no requirement to allow for draft angles or trim lines, the I-beam section of a PF rod is smoother than a DF rod (Fig. 33). Also, the inner radius in the web can be smaller for a PF rod, making possible a better mass distribution in the outer corners of the section where its contribution to stiffness is higher, added Ilia.

In the conclusion to the presentation other competitive advantages of PF rods over DF rods were enumerated by Ilia (although without supporting quantitative data):

- Higher material utilisation
- Better weight variation control (of significance in relation to NVH considerations)
- Better machinability
- Reduced numbers of machining operations
- Lower deformability during the fracture splitting process
- Lower overall cost in the finished machined product

Overall, the presentation provided compelling reasons for choosing the Powder Forging route.



Powder Forging Advantage:

- No trim line or draft angle
- 5% higher stiffness in XX-direction
- 15% higher stiffness in YY-direction
- Mass reduction opportunity (reduced cross-section) without loss of stiffness

Fig. 33 Ilia suggested further opportunities for light-weighting with PF con-rods [6] (Courtesy MPIF)

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Acknowledgements

PowderMet 2013 was organised by the Metal Powder Industries Federation. For more information please visit the MPIF website: www.mpif.org

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MPIF 2013 award winning Powder Metallurgy parts showcase an innovative industry

Winning parts in the Metal Powder Industry Federation's (MPIF) 2013 Powder Metallurgy Design Excellence Awards competition were announced at the PowderMet 2013 International Conference on Powder Metallurgy and Particulate Materials, Chicago, June 24-27. The awards provide a showcase for Powder Metallurgy, demonstrating the latest design and manufacturing developments in the industry.

It is clear from this year's MPIF Awards that conventional press and sinter Powder Metallurgy (PM) technology is continuing to find new applications in many sectors, whilst also replacing traditional manufacturing processes thanks to the design, performance and economic advantages that Powder Metallurgy offers.

The continuing growth in the Metal Injection Moulding (MIM) industry is also evident, reflected in the large number of prizes presented to this sector in this year's awards. MIM's growing acceptance in the automotive industry as a trusted manufacturing route is clear, with both a Grand Prize and Award of Distinction being presented to MIM companies in this demanding sector. The MIM process was also the manufacturing method of prize winners in the hand tools/recreation, aerospace/military and medical/dental categories.

Grand Prize Awards

Automotive engine

Indo-US MIM Tec Pvt. Ltd., Bangalore, India, received a grand prize in the automotive engine category for a sensing element, a threaded port, and a support ring made for Sensata Technologies Holland B.V., Almelo, the Netherlands (Fig. 1).

Made via the MIM process, these components are used in a sensor kit that measures the inlet pressure of the air fuel mixture in each cylinder of a passenger car engine. The length of the threaded port creates complexity, as do the thin walls and fragile features, and the stringent customer requirements on visual aspects add to the difficulty of manufacture.

Fig. 1 These MIM components are used in a sensor to measure the inlet pressure of the air fuel mixture in each cylinder of a passenger car engine (Courtesy MPIF)

Fig. 2 Compressor clutch used in a braking system for heavy trucks and buses (Courtesy MPIF)

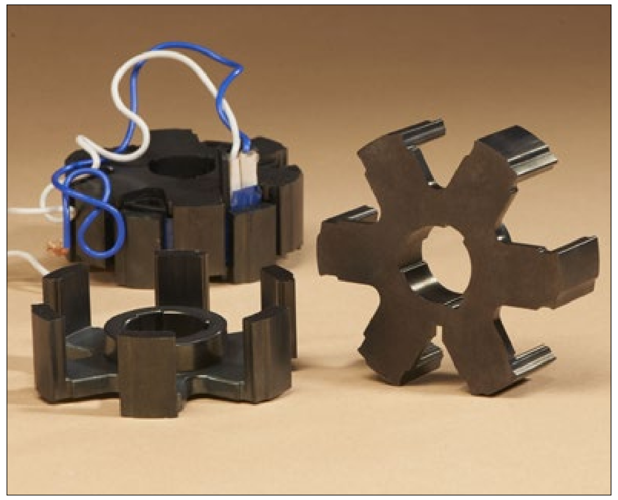

Fig. 4 These parts are used to generate a magnetic flux in a high efficiency brushless DC motor (Courtesy MPIF)

Fig. 3 Transmission rotor part used in large off highway construction vehicles (Courtesy MPIF)

Fig. 5 MIM tool holder assembly for a woodworking tool used in fine detail carving (Courtesy MPIF)

Made of MIM-17-4 PH stainless steel, the parts have a heat treated yield strength of 160,000 psi, ultimate tensile strength of 178,000 psi, 7% elongation, 35–40 HRC hardness range, and 7.6 g/cm³ density. The parts are formed close to net shape, with only coining and passivation required on all three, plus CNC thread cutting on the port only.

This new application is estimated to save the customer 50% over the cost of manufacture using alternative technologies.

Automotive chassis

AMES S.A., Barcelona, Spain, was awarded a grand prize in the automotive chassis category for a compressor clutch that is part of an assembly in a braking system for heavy trucks and buses (Fig. 2).

The system stops the compressor once the necessary air pressure is reached, which saves energy and helps reduce the vehicle's fuel consumption by 7%. Made of a diffusion alloyed steel, the complex part is compacted on a CNC 400 mt press at a pressure of >87,000 psi to achieve a required density >7.0 g/cm³. Other properties include 66,000 psi yield strength, 103,000 psi ultimate tensile strength, 1% elongation, and 85 HRB hardness.

The PM design integrates into a single component what was originally designed as two separate toothed parts - the conical front, which connects to the crankshaft, and the opposite face, which connects to the compressor and a coupling. The full shape of the large (nearly 1 kg) part, other than the outer grooves, is reached directly from compacting. Secondary processing includes sizing, turning, drilling two blind holes, and several finishing steps.

PM was the only technology capable of producing this part at the customer's cost target.

Lawn & garden/off highway

Capstan Tennessee Inc., Rockwood, Tennessee, USA, was given the grand prize in the lawn & garden/off highway category for a transmission rotor made for Caterpillar Inc., Peoria, Illinois. The rotor mates with a magnetic sensor that reads the rotating teeth to generate speed data used for controlling the shift point of transmissions powering large off highway construction vehicles (Fig. 3).

Made of carbon steel, this single level part is pressed to a density of 6.85 g/cm³, sintered, and then re-pressed to 7.00 g/cm³. Other final properties include ultimate tensile strength of 30,000 psi, 20,000 psi min. yield strength (2% offset), and 75 HRF min. hardness. The 7.795 in. dia. is held within 0.006 in., while the angularity of the 40 teeth is maintained within ±1 degree. The 805 g part is pressed to net shape, with the drilling of the five true position holes being the only secondary operation.

In addition to the saving of 63% over the cost of machining, the critical thickness, flatness, and parallel tolerances maintained in its manufacture make the rotor a truly outstanding PM part.

Hardware/appliances

Claw pole motor core stators made by Burgess-Norton Mfg. Co., Geneva, Illinois, won the grand prize in the hardware/appliances category. The parts are used to generate a magnetic flux that interacts with a rotor and permanent magnets to produce torque in a high efficiency brushless DC motor in an electric ceiling fan (Fig. 4).

Both halves of the motor core are produced using one set of tools: heated fixed fill shelf die, core rod, single upper punch, and six thin walled lower fill punches. Formed from a high compressibility inorganically insulated iron powder, the parts are compacted with pressures exceeding 67 tsi to a density range of 7.4–7.5 g/cm³, typical ultimate tensile strength of 7,000 psi, and 19,000 psi transverse rupture strength. The parts are compacted to net shape and require no secondary operations.

They belong to a new generation of DC motors using soft magnetic composite PM materials to enable greater design freedom for designers of electric machines.

Hand tools/recreation

Indo-US MIM Tec Pvt. Ltd., Bangalore, India, received the grand prize in the hand tools/recreation category for a tool holder assembly made for Scintilla AG, Solothurn, Switzerland. The assembly that incorporates these two MIM parts, a tool holder and a grip spring tensioning part, goes into a woodworking tool for fine detail carving (Fig. 5).

Part complexity made MIM the obvious choice as no other technology could produce the part as an integral unit and deliver it in the needed volumes at the target cost. Made of a low alloy steel, the parts are supplied in the heat treated condition. Properties include 7.5 g/cm³ minimum density, 225,000 psi ultimate tensile strength, and 200,000 psi yield strength. To overcome the possibility of distortion on the unsupported open end, the design provided supporting ribs. The grip support ring was produced per print with the help of one turning operation.

The MIM design contributes to a lean operation for the customer by substantially reducing lead time through the elimination of many processing steps.

Aerospace/military

Polymer Technologies Inc., Clifton, New Jersey, USA, were presented with the grand prize in the aerospace/military category for two MIM parts, a U-bracket and stop used in a Feedbox Support Improvement Kit (FSIK) for an M249 squad automatic weapon (SAW) used by the US Military (Fig. 6).

The device is designed to hold various size high volume magazine ammunition packs securely to the gun. It extends the service life of the weapon by enabling the soldier to repair it in the field, thus avoiding the cost of a new weapon.

Drop testing of the firearm with the device attached proved the integrity of the FSIK even while other components were damaged. The innovative I-beam and webbing design allowed the parts to meet the 32–38 HRC hardness range requirement and still maintain the total weight of the kit below 3.5 oz.

Moulded from MIM-17-4 PH stainless steel, the parts have >7.5 g/cm³ density, 130,000 psi ultimate tensile strength, 106,000 psi yield strength, and 6% elongation. The only secondary processing of these near net shaped parts are a coining operation to the bracket in order to achieve the tolerance required for the distance between the notch and the through hole, as well as tapping the hole to provide necessary threading. Both parts are black oxided to remove their reflective properties, a critical consideration for the safety of the soldier.

Fig. 6 MIM parts for a component used in the M249 squad automatic weapon used by the US Military (Courtesy MPIF)

Fig. 7 Stainless steel jaw made for a medical grasping device (Courtesy MPIF)

Medical/dental
FloMet LLC/A QMT Company, Deland, Florida, USA, was awarded the grand prize in the medical/dental category for a 17-4 PH stainless steel jaw made for US Endoscopy, Mentor, Ohio, and used in a Raptor™ grasping device (Fig. 7).

Made via MIM, the jaws merge into one design that features both a rat tooth jaw and an alligator jaw, combining the functions of a grasper and a retrieval forceps that surgeons use to retrieve foreign objects in the body during minimally invasive procedures.

The component design is enormously complex due to its small size, thin wall requirements 0.25 mm (0.010 in.), and features required to achieve full functionality with the sharp talons and teeth at net shape. The parts have >7.5 g/cm³ density, 130,000 psi ultimate tensile strength, 106,000 psi yield strength, 6% elongation, and 27HRB hardness. Only minimal secondary processing (coining to help maintain the alignment of the jaws) was needed, as other geometries and tight tolerances were achieved in the as moulded condition.

Alternative processing methods could not have achieved the part's intricate geometries at a reasonable cost. MIM is estimated to have saved more than 60% over die casting or machining the parts.

Awards of Distinction

Automotive engine
Indo-US MIM Tec Pvt. Ltd., Bangalore, India, won the first award of distinction in the automotive engine category for a fuel control gear segment made for Bosch Limited, Bangalore, India (Fig. 8). The part goes into a fuel control device that regulates the entry of fuel into the engine.

Converted from a machined part, the gear segment is fabricated via MIM from a low alloy steel at a saving of 80% over the previous method. Moulded to net shape and requiring no secondary operations, the part has a density of 7.5 g/cm³, 46,000 psi ultimate tensile strength, 19,000 psi yield strength, 25% elongation, and

Fig. 8 Fuel control gear segment of a fuel control device that regulates the entry of fuel into the engine (Courtesy MPIF)

Fig. 10 This ramp plate is used in an electronically activated locking differential in light commercial vehicles (Courtesy MPIF)

Fig. 9 Aluminium rear cam cap used in a new automotive engine design (Courtesy MPIF)

Fig. 11 This copper infiltrated PM steel inside hub adaptor is used in electronic door lock systems (Courtesy MPIF)

Fig. 12 The rack, pinion, and bushing are components used in a pergola louver system (Courtesy MPIF)

Fig. 13 This MIM actuator is used in a tool less locking system that enables quick changing of a shotgun stock (Courtesy MPIF)

100 HRB max. hardness. Nearly three million pieces are delivered annually to the customer.

Automotive engine
GKN Sinter Metals LLC, Conover, North Carolina, USA, won the other award of distinction in the automotive engine category for an aluminium rear cam cap (Fig. 9). Used in a new automotive engine, the part serves a dual function of holding the camshaft in place as well as holding an auxiliary vacuum pump.

This is the first time an aluminium cam cap with the unique tombstone geometry has been manufactured via press and sinter PM. Until the present redesign, in which the part is compacted inverted, this feature could only be formed via die casting.

The part is formed to near net shape with only the cover seal area being CNC machined. Properties include 2.55 g/cm³ density, 22,000 psi ultimate tensile strength, 17,000 psi yield strength, and 60 HRE min. apparent hardness.

Automotive transmission
The award of distinction in the automotive transmission category was won by Burgess-Norton Mfg. Co., Geneva, Illinois, USA, for a ramp plate used in an electronically activated locking differential in European light commercial vehicles (Fig. 10). These differentials significantly improve on demand vehicle traction in adverse conditions by directing 100% of the drive torque simultaneously to both wheels.

Made using FL-4400 prealloyed steel, the parts are pressed, sintered, soft turned, heat treated (Q&T) and then hard turned to generate concave back face features. Unique processing and part density enable the production of a component that exhibits the strength and wear properties of FL-4405-125HT on the ramp face and soft magnetic properties on the back face.

The use of PM provided cost savings estimated at 20-40% over machining a component with similar functional performance.

Hardware/appliances
ASCO Sintering Co., Commerce, California, USA, won an award of distinction in the hardware/appliances category for an inside hub adaptor, made for Ingersoll Rand Security Technologies (Schlage), Carmel, Indiana (Fig. 11). The copper infiltrated PM steel part is used in modern, high end electronic commercial and residential door lock systems including the latest touch screen devices.

The part has seven functional levels that are pressed using three upper punches, two separate shelf levels, and two lower punches, with a proprietary triple upper actuating mechanism used to achieve extensive powder transfers and fill compensation. The adaptor is pressed to net shape with plating as the only secondary operation performed. Properties include 7.7 g/cm³ density, 95,000 psi ultimate tensile strength, 8% elongation, 100 ft.-lb. unnotched Charpy impact energy, and 90 HRB hardness. Aggressive PM part design yielded 40% savings over alternative methods.

Hardware/appliances
FMS Corporation, Minneapolis, Minnesota, USA, also won an award of distinction in the hardware/appliances category for an assembly consisting of a rack, pinion, and bushing used in a patented pergola louver system that allows the pergola to convert to a water tight shelter (Fig. 12).

The sinter hardened steel rack and five level pinion and the copper steel bushing are pressed to net shape with one cross drilled hole being the only secondary operation performed. The assembly was designed to be sinter bonded for strength.

The parts have a typical density of 6.7 g/cm³, 75,000 psi ultimate tensile strength, 135,000 psi transverse rupture strength, and 20 HRC min. apparent hardness and 52 HRC min. particle hardness. Because of the large number of assemblies required in each louver system, the PM process gave the customer the only cost effective option, delivering an estimated 75% savings over the machined alternative.

Hand tools/recreation
An award of distinction in the hand tools/recreation category was earned by Parmatech Corporation, Petaluma, California, USA, for an actuator used in a tool less locking system that enables quick changing of a shotgun stock (Fig. 13).

Made via MIM of a low alloy steel,

Fig. 14 A star shifter used in a six speed motorcycle transmission system (Courtesy MPIF)

Fig. 15 MIM stainless steel shuttle used in a stapling device for arthroscopic surgery (Courtesy MPIF)

the complex design part required the use of stepped ejector pins on the sloped surface to allow for smooth ejection with no part damage. It has a 0.05 mm (0.002 in.) straightness requirement of the longer than 25.4 mm (1 in.) shaft and a tight profile requirement of the curved and sloped cosmetic surface. The part is moulded and sintered close to net shape to 7.48 g/cm³ density, and is coined in order to achieve repeatability.

Choosing MIM over casting and machining the part provided a cost savings of 25–35%.

Hand tools/recreation

A star shifter made by FMS Corporation, Minneapolis, Minnesota, USA, for Polaris Industies, Wyoming, Minnesota, and used in its Victory motorcycle transmission, won another award of distinction in the hand tools/recreation category (Fig. 14).

The first PM component in this six speed transmission, it functions as the cam interface in a mechanism that enables the engagement and shifting among all the gear combinations. This six level part is made of sinter hardened steel, moulded in a CNC servo controlled, multi action hydraulic press to a typical density of 6.65 g/cm³. Other properties include 75,000 psi ultimate tensile strength, 135,000 psi transverse rupture strength, and 20 HRC min. apparent hardness and 52 HRC min. particle hardness.

The customer estimates a 45% cost savings over the previously forged part.

Medical/dental

Polymer Technology Inc., Clifton, New Jersey, USA, received the award of distinction in the medical/dental category for a stainless steel shuttle used in a smart stapling device for both open and minimally invasive arthroscopic surgery (Fig.15).

It is part of a device that interacts with a disposable staple cartridge in a computer controlled device that provides a high level of precision, consistency, accuracy, agility and compressive force for the surgeon using it.

Manufactured via MIM, the shuttle incorporates two separate components that previously were combined via laser welding. Making this intricate, small, and lightweight 0.175 oz. component presents many challenges, including the extremely thin walls, tight radii, and true position geometries, especially the two leg tips, which need to maintain their required strength and piercing sharpness. Part properties include 7.75 g/cm³ density, 200,000 psi ultimate tensile strength, 160,000 psi yield strength, 11%-30% elongation, and 82 HRB hardness.

The shuttle is formed to nearly net shape, requiring only minimal secondary operations of reaming and then tapping the small hole, as well as providing proprietary sintering fixtures to maintain the straightness callout for the parallel walls.

Soft Magnetic Composites in the development of a new compact transversal flux electric motor

With growing demand for electric motors used in practically all sectors, the number of applications for sintered and non-sintered Soft Magnetic Composite (SMC) materials based on soft magnetic iron powders is increasing significantly. GKN Sinter Metals and RWTH Aachen have collaborated to develop a new transversal flux motor (TFM) which uses SMC iron powders in the stators of the motor. We report on a presentation given by Stefan Tiller, GKN Sinter Metals, at the Coil Winding Expo, Berlin, Germany, June 26-28 2013, on the development of the new TFM e-motor.

Transversal flux motors (TFMs) and their applications in direct drive systems is a relatively recent development in electric motors which demand high torque at low speed and where the elimination of a gearbox can result in a compact design, reduction in iron losses, and less maintenance. TFMs can offer a high percentage size reduction compared with conventional e-motors, and with only small masses rotating in the rotor supported by axial magnetic forces, the result is also a low-noise electric motor. Another benefit is the reduction of the copper content in TFMs which leads to lower costs as well as less weight compared with traditional radial flux motors and the popular axial flux motor (Fig. 1)

GKN Sinter Metals has been working to produce a new prototype transversal flux motor under a development project called Elektra, supported by the RWTH University of Aachen, Germany, in which GKN Sinter Metals uses a stator produced out of Soft Magnetic Composite (SMC) iron powder. The new TFM motor, which was introduced for the first time at the Coil Winding Expo – CWIEME in Berlin in June 2013, is around 50% smaller and uses 40% less copper than an industry standard brushless radial flux motor of a current white goods application, yet creates higher power density.

In its basic form the TFM prototype

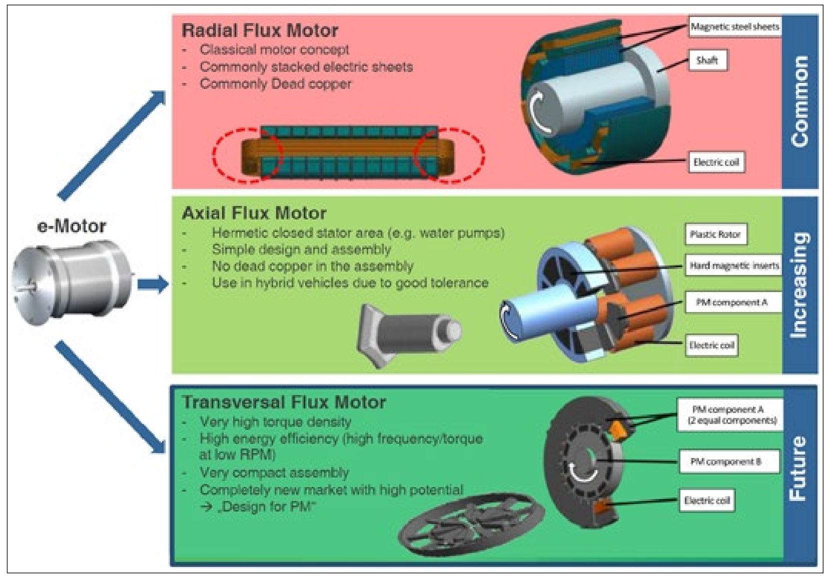

Fig. 1 Comparisons of various electric motor concepts [1] (Courtesy GKN Sinter Metals)

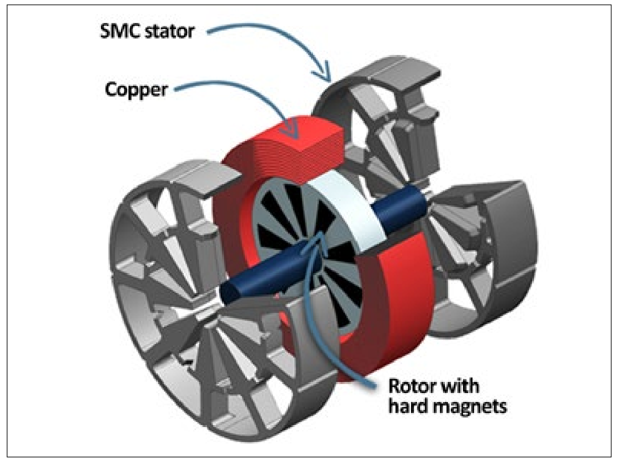

Fig. 2 Basic design of the transversal flux motor developed jointly by RWTH Aachen University and GKN Sinter Metals [1] (Courtesy GKN Sinter Metals)

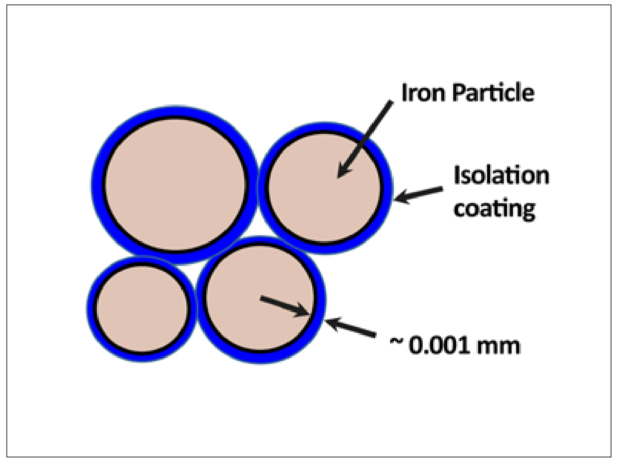

Fig. 3 Each SMC iron powder particle is given an electric isolation layer [1] (Courtesy GKN Sinter Metals)

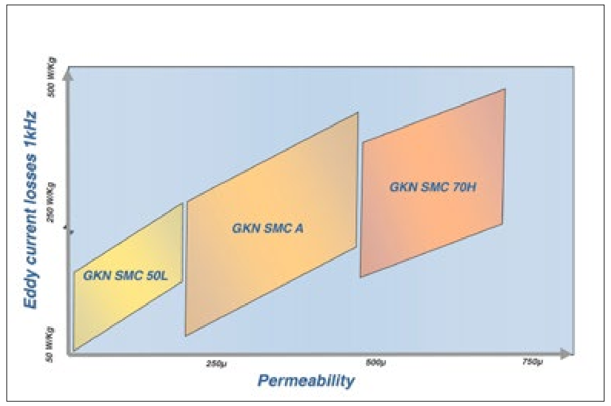

Fig. 4 Eddy current losses 1 kHz and permeability of three SMC grades used by GKN Sinter Metals for soft magnetic components [1] (Courtesy GKN Sinter Metals)

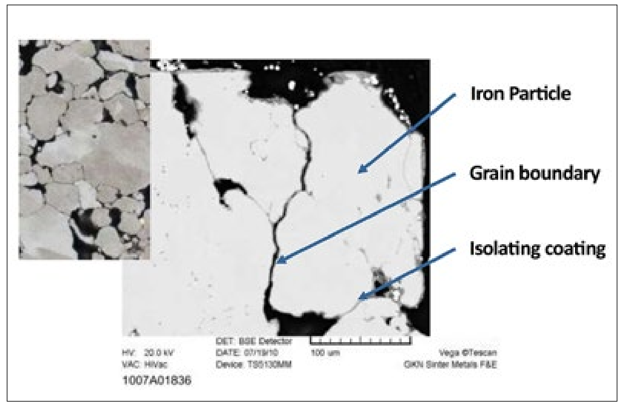

Fig. 5 Microstructure of SMC compacts showing the isolation coatings [1] (Courtesy GKN Sinter Metals)

developed by GKN Sinter Metals and RWTH Aachen consists of a stator element made from one of the SMC grades used by GKN Sinter Metals, a copper winding and a rotor with a NdFeB permanent magnet (Fig. 2).

In order to produce a TFM motor with an output of 1 kilowatt, three phase elements have to be assembled in line with a displacement of 120 degrees each. Higher performance can be achieved with a modular design of several phases assembled in line. Their frequencies can range from 100 Hz up to theoretical 20 kHz.

Soft Magnetic Composite iron powders used in TFMs

The Soft Magnetic Composite chosen by GKN Sinter Metals to produce the stators is based on a high purity, high compressibility iron powder grade, GKN SMC A, where each powder particle (<0.2 mm) is coated with a resin-based material to create an electric isolation layer ~0.001 mm thick (Fig. 3). The eddy current losses and permeability properties of GKN SMC A grade and two other SMC grades used by GKN Sinter Metals are shown in Fig. 4.

GKN Sinter Metals uses a compaction pressure of 75 kN/cm² to achieve a green density of 7.5 g/cm³ in the GKN SMC A grade material. After pressing the compacts are heat treated at temperatures between 200 - 600 °C to anneal and cure the bond, and to obtain mechanical strength of approx. 125 N/mm². As can be seen in Fig. 5 the isolation layer remains intact in the microstructure to give three-dimensional (isostatic) magnetic properties in the SMC stator with significantly reduced eddy current losses. Following curing the TFM stators (Fig. 6) can be coated, steam treated and machined, if needed.

"Higher performance can be achieved with a modular design of several phases assembled in line. Their frequencies can range from 100 Hz up to theoretical 20 kHz"

The GKN SMC A material used to produce the stator cores for the TFM prototype showed high maximum saturation induction of 1.6 to 1.7 T at the density of 7.5 g/cm³, high permeability (650) and had low iron losses (91.8 W/kg at 1 kHz (0.75T)). The isotropic magnetic properties and low eddy current losses of three dimensional transversal flux machines is achievable only by using SMC powder materials. The influence of different section densities in the SMC stator also increases magnetic efficiency by gearing the magnetic flux density.

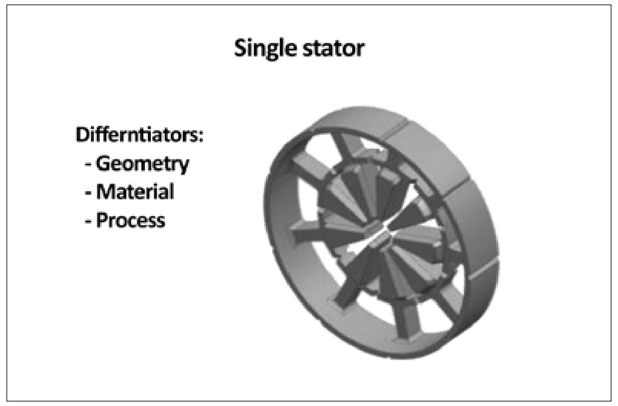

Fig. 6 Complex geometry of the SMC stator produced by GKN Sinter Metals to high dimensional accuracy for use in the Elektra TFM [1] (Courtesy GKN Sinter Metals)

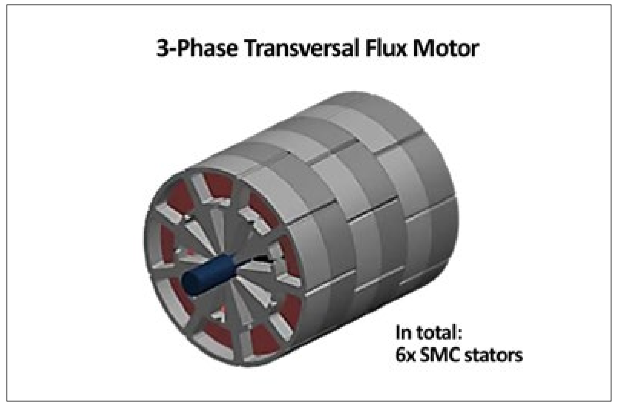

Fig. 7 Assembly of a 3-phase Elektra transversal flux motor using six SMC stators [1] (Courtesy GKN Sinter Metals)

Design advantages

Key design advantages of the Powder Metallurgy route in producing the TFM stators is the ability to design magnetic circuits with three-dimensional magnetic flux paths to overcome the restraints imposed on the magnetic field by steel laminations. This allows different topologies to be exploited for high electric motor performance. An other advantage is the high precision which can be achieved in the complex shape compacts (ISO Class 8) to reduce air gaps and to ensure better positioning and a smooth silent run.

The Elektra transversal flux motor development programme undertaken jointly by RWTH Aachen and GKN Sinter Metals involved the evaluation of a number of possible motor concepts. This included three dimensional modelling of the various concepts and FEM simulation to determine magnetic performance and efficiency of the electric motors. The result is the 3-phase TFM shown in Fig. 7. This shows the assembly of the first SMC stator with pre-wound copper coil being directly placed into the stator using simple circular winding. The simple winding method eliminates expensive copper wiring equipment, makes full use of the copper by enabling a high packaging rate and leaves no dead copper in the system.

"Key design advantages of the PM route in producing the TFM stators is the ability to design magnetic circuits with three-dimensional magnetic flux paths to overcome the restraints imposed on the magnetic field by steel laminations"

These are then assembled onto an assembly shaft with a permanent magnet rotor, and the second stator is added to complete the 1st phase. The poke yoke design of the stator ensures perfect orientation of the phases to each other. It is then possible to proceed with the 2nd phase, and optionally a 3rd phase can be added to increase the power of the Elektra motor.

When compared with a conventional electric motor the Elektra TFM has a significantly smaller motor volume, higher torque density, and, as mentioned earlier, lower noise level due to the harmonic frequency output of the Sinus pole geometry and also low cogging characteristics.

GKN Sinter Metals states that potential e-motor applications below 1 kW, suitable for the advantageous transversal flux and axial flux motors including SMCs are new e-bike motors, water and oil pumps, small generators, starter motors, fan motors for vehicles and further domestic white good appliances, to name just a few.

For more informaton visit:
www.gkn.com/softmagnetic

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[1] From presentation by Stefan Tiller: "New opportunities in the development of cost- and power-efficient electric motors using PM produced parts" at CWIEME 2013, Berlin, June 2013).

Scan this QR code to watch the animation "New Generation Electric Motor with PM4EM" on YouTube. The video gives detailed insight to the new "Elektra" Transversal Flux Motor (TFM) project.

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November 3-6
Xiamen, China
www.apma2013.com

Hagen Symposium (32nd)
November 28-29, 2013.
Hagen, Germany
www.pulvermetallurgie.com

2013 International Titanium Powder Processing, Consolidation and Metallurgy Conference
December 2-4 Waikato, New Zealand
www.tida.co.nz

2014

PM14 - International Conference on Powder Metallurgy and Particulate Materials & Exhibition
January 23-25, Chennai, India
www.pmai.in/pm14

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

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

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

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