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SUMMER 2013

POWDER METALLURGY REVIEW

HIP OF LARGE PM PRODUCTS

ADVANCES IN POWDER COMPACTION

HAGEN SYMPOSIUM, PM-13 INDIA

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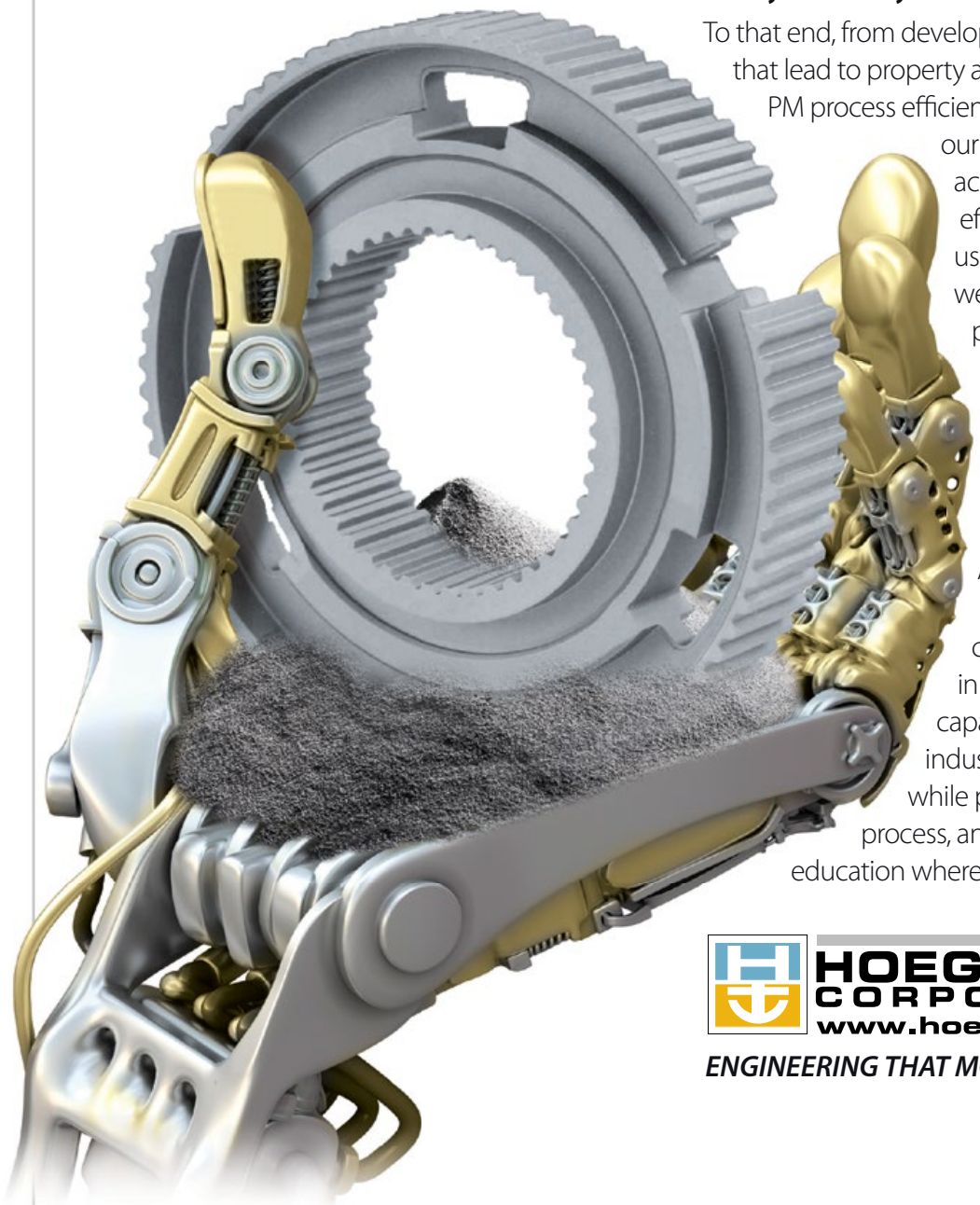

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Submitting news and articles
We welcome contributions from both industry and academia and are always interested to hear about company news, innovative applications for PM, technology developments, research and more.

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POWDER METALLURGY REVIEW

Developments in PM processing open up new possibilities

In this 80 page issue of *Powder Metallurgy Review* we present a comprehensive report on the Hot Isostatic Pressing of large PM products. Whilst HIP technology has for many decades enabled the production of relatively large PM parts, recent developments in large scale HIP systems now offer the potential for even larger components. In our exclusive report Dr Stephen J Mashl outlines the development of these large HIP systems and highlights the improved properties and cost savings that HIP processing can offer (page 31).

The continuing developments in conventional powder compaction technology are also providing increasing opportunities for the production of complex PM components. Professor Dr-Ing Paul Beiss identifies the latest advances in die compaction technology from Europe's press and tooling systems manufacturers (page 41).

Along with our sister publication *Powder Injection Moulding International*, we recently exhibited at the "2013 China International Power Metallurgy Exhibition & Conference" in Shanghai, China. The event proved to be significantly larger than in previous years and attracted visitors from throughout China and further afield. As the only PM industry publisher present at the event we were delighted with the level of interest in both our print and on-line publications.

Powder Metallurgy Review was also distributed at the "PM-13 International Conference & Exhibition on PM for Automotive and Engineering Industries" in Pune, India. We report on this important international conference and highlight some of the key presentations (page 59).

We also report on the 2012 Hagen Symposium, the annual meeting for German speaking powder metallurgists (page 49).

We hope you enjoy this latest issue of *Powder Metallurgy Review.*

Paul Whittaker
Editor, *Powder Metallurgy Review*

Cover image
Powder forged connecting rods manufactured by Metaldyne LLC (Courtesy Metaldyne)

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Summer 2013

POWDER METALLURGY REVIEW


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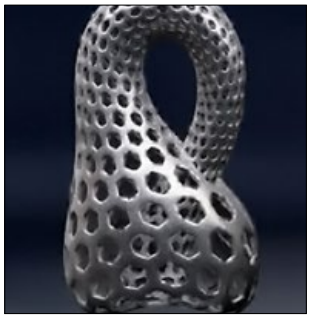
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regular features

industry news

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

Metal Powder Products continues expansion of its PM operations

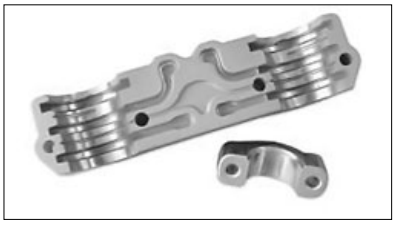
Metal Powder Products (MPP), headquartered in Westfield, Indiana, USA, has announced the recent installation of additional powder compacting presses and furnaces at its PM plants in the St. Marys area of Pennsylvania, USA.

Having already added Alpha 250 ton and Gasbarre 30 ton powder presses at its Ridgway plant late last year, MPP recently announced that it has added a 400 ton Gasbarre powder press at its Ford Road plant in St. Marys.

The investment in the new presses was required to increase capacity for contracts for newly tooled business, stated Jesse Azzatoi, General Manager of MPP's St Marys operations. The installation of the 400 ton press adds to the high tonnage capability (up to 900 tons) at MPP.

MPP also recently installed a 30 inch high capacity Abbott sintering furnace at its Washington Street facility in St Marys in order to increase capacity for new orders received over the past year.

The company was recently recognised in Wards Automotive as one of the key suppliers to the ten best automotive engines for 2012. Two of the winners were Chrysler's 3.6L Pentastar, which is used in various applications, and Ford's 5.8L supercharged V-8 powering the Shelby GT500 Mustang. Metal Powder Products supplies powder metal aluminum powertrain parts for both engines. Included are PM camshaft bearing caps which have been in production at the Washington Street plant since late 1992. Since that time MPP has produced more than 45 million cam caps from PM aluminium.



Powder metal aluminium dual front caps produced MPP. Left is a cap for a DOHC V6 engine and right a single front cap for a DOHC V8 engine

www.metalpowder.com

PMG to build second manufacturing facility at US site

PMG group has announced an investment of some $23 million to build a second manufacturing facility on its 40-acre campus in Columbus, Indiana, USA.

The 36,000 ft^2 facility, which is expected to be completed by the end of the year, will accommodate two new manufacturing lines. In addition, a third line will be installed in an existing plant. With this expansion PMG will create up to 50 new jobs by 2014.

PMG is headquartered in Füssen, Germany, and currently has six plants in four countries (Germany, Spain, USA, China). The group employs around 1250 people and has annual turnover of around €210 million. The company manufactures a wide range of sintered components and systems for the automotive industry.

www.pmgsinter.com

Federal-Mogul sells its Sintertech SAS Division

Federal-Mogul Corporation's Powertrain Segment has announced the sale of its Sintertech SAS division to TMC, a closely held subsidiary controlled by Thierry Morin, French Industrialist and former Chairman and Chief Executive Officer of Valeo Corporation.

Sintertech develops, produces and sells powdered metal components for engines and gearboxes for vehicle applications and other industrial equipment, as well powdered metal filtration elements mainly for the chemical industry under the brand names Sintertech, Metafram®, Metagliss® and Poral®.

The transaction agreement was completed on March 8 2013. Details of the transaction were not disclosed.

"The Sintertech businesses are well-known in Europe for producing near net shape powdered metal components for a wide variety of applications in various industries, however these businesses are not core to Federal-Mogul Powertrain's long-term portfolio strategy," stated Rainer Jueckstock, Federal Mogul's co-CEO and CEO Federal-Mogul Powertrain.

"The Sintertech businesses will benefit from the industrial experience, customer contacts and focused management expertise of Thierry Morin and his team. We will work with them to ensure a smooth transition for customers and other stakeholders," added Jueckstock.

The Sintertech business includes three manufacturing plants in France located in Veurey-Voroize, Pont de Claix and Oloron with more than 400 employees.

www.federalmogul.com

$6 million investment at Schunk's Mexican Sintermetal plant

Sintermetal S.A. de C.V has announced an investment of some $6 million at the company's site in Mexico, with the opening of its latest plant expansion at their facility in Ocoyoacac.

Founded in Mexico in 1966 and acquired in 1995 by the Schunk Group, Sintermetal manufactures a wide range of sintered parts for numerous applications. New machinery incorporated in the expansion will offer the highest standard of control, allowing Sintermetal to expand its reach into the market of highly complex sintered parts, stated the company. This will enable Sintermetal to produce rotors for oil pumps and VVT (variable valve timing) systems, among other applications.

Schunk Group's head office, located in Germany, approved this significant investment to meet the needs of the domestic market as well as North and South America. "This expansion is due to the growing niche market in which there is a strong tendency to have suppliers with the best quality standards worldwide and short response times. Sintermetal offers these advantages to serve its customers in time with the quality required, eliminating the need to buy sintered parts from Europe or Asia."

Sintermetal's new machining room

CEO of the Schunk Group, Gerhard Federer (right), at the opening of the new facility

In attendance at the opening ceremony on January 21 was Gerhard Federer, CEO of the Schunk Group, as well as representatives from the CAMEXA (Mexican-German Chamber of Commerce and Industry).

www.schunk-group.com

Ceratizit expands cutting tool production in India

Ceratizit SA has announced the expansion its cutting tool business in India with the establishment of a new production unit at its 6.2 acre site in the industrial area of Uluberia, West Bengal.

Ceratizit India has been manufacturing hard metal products in Bengal for some seventeen years and the new production plant will see a further 200 job opportunities created.

"To meet the increasing demand of cutting tools in Asia, this continuous expansion and strengthening of our activities in the important Indian market is key to our success," stated Thierry Wolter, member of the Ceratizit Executive Board.

The official inauguration ceremony took place on April 24 2013, in presence of the Ambassador of Luxembourg to India, Gaston Stronck, the Managing Director of Ceratizit India Pvt. Ltd., Ashwani Sareen, as well as the Ceratizit Representative for the Executive Board Jacques Lanners and Executive Board member Thierry Wolter.

www.ceratizit.com

OM Group completes sale of its cobalt business for $325 million

The OM Group, Inc., based in Cleveland, Ohio, USA, has completed the previously-announced divestiture of its Advanced Materials division, which includes the production of extra fine cobalt powders and value-added nickel-based products. The division has been bought by a joint-venture consortium comprising Freeport-McMoRan Copper & Gold Inc., Lundin Mining Corp. and La Generale des Carrieres et des Mines (Gecamines) for $325 million cash, plus approximately $30 million for cash retained in the business, upon the closing of the transaction.

Following the sale, to assist the buyer of the downstream business with the ownership transition, the OM Group will act as an intermediary of cobalt supply between GTL and the Freeport joint venture under a two-year agreement subject to delivery of 7,000 mt of feed. The OM Group will also continue to serve as the US distributor for refined cobalt products for a period of one year.

The OMG Group reported an 8.1% increase in sales in 2012 to $1,637 million with the Advanced Materials division contributing 27%. In 2011, OMG Group acquired Vacuumschmelze (VAC), to provide a new growth platform in the Magnetic Technologies sector. The acquisition gives OMG access to diverse end markets using magnetic materials with a focus on technology and innovation and with potential growth paths. The Magnetic Technologies division contributed 39% to sales in 2012.

Sandvik to acquire Canadian drilling solutions provider

Sandvik has signed an agreement with Cubex Limited to acquire its drilling solutions business and operations.

Cubex is an industry-leading drilling solutions provider focused on design and manufacturing of a wide range of underground in-the-hole, and geo-technical drilling equipment.

In 2012, the acquired business of Cubex had a turnover of around 270 MSEK and some 110 employees. The head office and manufacturing facility is based in Winnipeg, Canada. The acquisition is expected to be completed during the second quarter 2013.

www.sandvik.com
www.cubex.net

Tenova acquires furnace manufacturing group Metall Technologie Holding

LOI Thermprocess GmbH, a subsidiary of Tenova, has signed an agreement with European Capital S.A. SICAR for the acquisition of the Metall Technologie Holding Group (MTH). MTH is headquarted in Menden (Germany) and controls Schmetz, Mahler and IVA in Germany, BMI in France and Huisen in China.

The MTH group, a leading provider of industrial vacuum and atmospheric furnaces, currently employs 320 people with a turnover of around €65 million. MTH currently serves an installed base of around 2,500 heat treatment furnace units.

"This acquisition reinforces Tenova's position in the heat treatment furnace industry," stated Alberto Iperti, CEO of Tenova, "MTH adds a growing segment with a high quality product, production process and after-sales services."

Mahler manufactures a range of furnaces for the PM industry, including this 450mm conveyer belt sintering furnace (Courtesy Mahler)

Gianfelice Rocca, Techint Group Chairman added, "The acquisition of MTH confirms the growth of Tenova in Germany. Tenova's total number of employees in Germany will approach 1000 across a variety of industrial companies with significant technology intensity such as MTH itself and the other Tenova's subsidiaries including LOI Thermprocess GmbH, Takraf GmbH and Re Energy GmbH."

www.mth-group.com

Brazilian furnace manufacturer Engefor bought by Seco/Warwick Group

Seco/Warwick has announced the purchase of Brazilian heat treatment manufacturer Engefor based in the industrial belt of Sao Paulo City in Jundiai, Sao Paulo State.

Engefor has been serving the Brazilian Market with furnaces and equipment for more than 20 years. The former owners of the company, Aparicio Vilademir Freitas and Yassuhiro Sassaqui, will remain in the management of the company and will be joined by Thomas Kreuzaler, who will take a seat for the Seco/Warwick Group.

Seco/Warwick plans to extend the scope of products offered by Engefor and will integrate the company's manufacturing and service capabilities in its international network. Engefor will change its name to Seco/Warwick do Brasil, Industria de Fornos Ltda.

www.secowarwick.com

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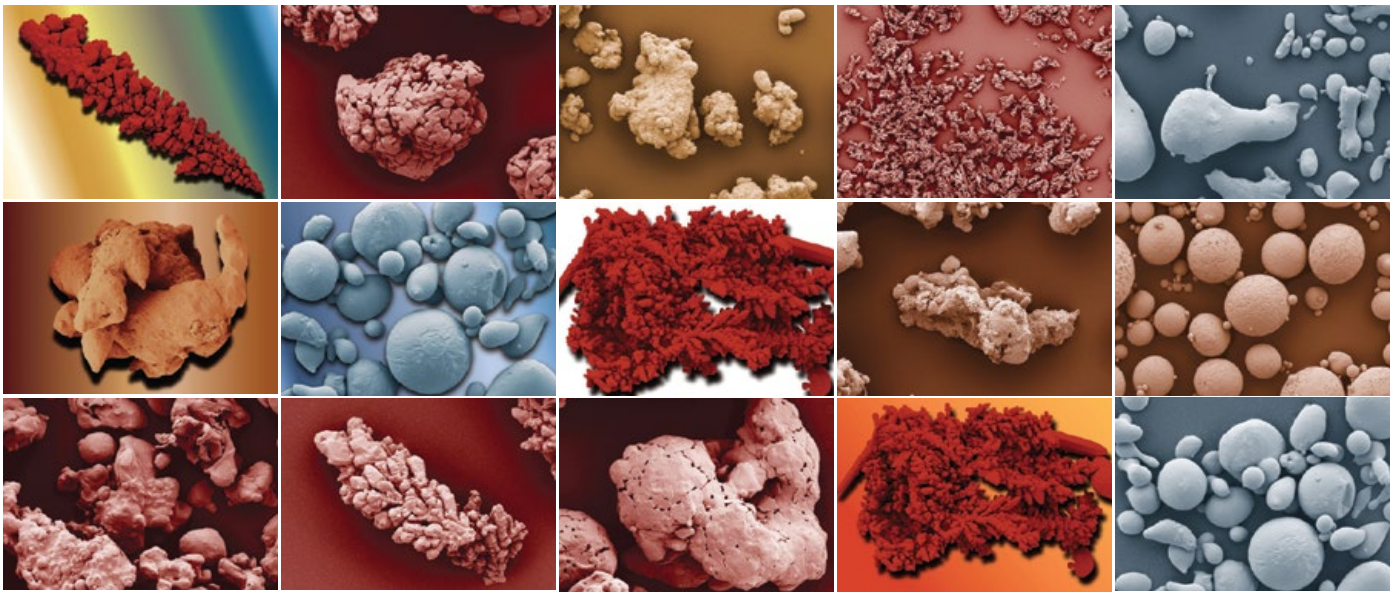

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Höganäs CEO Alrik Danielson reviews a challenging 2012

In Höganäs AB's 2012 Annual Report, CEO Alrik Danielson reviewed what was a difficult year for all companies connected to the global automotive industry. The report also highlighted a number of positive developments that took place at Höganäs during the year.

"Just like every other company in 2012, we were affected by the global economic downturn in the second half-year," stated Danielson, "This resulted in somewhat lower sales, of SEK 6.7 billion, down 5% on 2011. We were also affected in profit terms, but still succeeded in achieving an operating margin of 14.1% excluding restructuring expenses in the fourth quarter, compared to our long-term target of 15%."

"2012 started better for Höganäs than we had expected. In the first quarter, we achieved good sales performance and market acceptance of new powder products in surface coating and component manufacture was positive. Then, in the spring, we saw a clear demand slowdown—our customers, and their customers, were affected by a weak business cycle. Our sales and order levels deteriorated gradually quarter by quarter. We adjusted the production rates in our plants accordingly."

"The savings actions we initiated in autumn 2011 continued, but were not enough. So in autumn 2012, we started a major rationalisation programme to adapt our capacity to market demand and cut our costs."

The impact of reduced car production

"Our Components business area consists of powder manufacture and sale to component manufacturers. Its customers are mainly in the powder metallurgy industry, who often produce large batches. Decreasing car production, especially in Europe, combined with generally lower industrial production, negatively affected the business area's progress. Demand from subcontractors for garden equipment, tools and household appliances also levelled off. However, the launch of the latest generation of metal powder solutions for component manufacturers was successful in many markets. Overall, Components' turnover was down somewhat on 2011," added Danielson.

Regional trends

Commenting on regional market variations, Danielson explained, "Höganäs' performance on its geographical markets was mixed. Sales in Europe decreased in the year due to the economic slowdown. The European car industry is struggling with overcapacity, the estimated capacity surplus in 2012 is 2-3 million cars, or 15-20%. Sales in Asia progressed positively, especially in the first half-year, with sales recovering after the Japanese tsunami and flooding in Thailand. Sales in most Asian countries were fairly good in the year, while progress in India slowed due to factors including the country's economic problems. Our underlying sales in North America are positive, while the South American market started poorly, but improved in the year, through means including growth-promoting stimulus measures for the Brazilian economy."

A move towards new technologies: Inductors, MIM and Additive Manufacturing

Commenting on Höganäs' move into new market areas, Danielson stated that, "The launch of Inductit [Höganäs' own inductors] in the spring gained a very positive market reception. The first orders were shipped in the second quarter and deliveries continued for the rest of the year. The development of injection-moulded components based on our metal powder, termed Metal Injection Moulding, MIM, is another good example of new applications. The combination of unique production technology and the right binding agents enable the usage of coarser powders for larger MIM components, for applications such as medical and dental instruments, tools and household products. This coarser powder can be produced at a lower cost, enabling the production of larger components for a relatively low cost. This will mean lower costs for our customers compared to traditional, finer MIM powders."

Höganäs' acquisition of Fcubic AB and the formation of the Digital Metal® segment sees the company making a move into the rapidly evolving area of Additive Manufacturing (AM). Commenting, Danielson stated, "This acquisition is an important step towards strengthening our competence in additive manufacturing, or 3D printing. We expect Digital Metal's technology to be an important part of component and system manufacture of the future, because it creates significant value for customers for minimum development lead-times, superior performance and customer-specific components on a large scale."

Höganäs moved into additive manufacturing with the acquisition of Fcubic, rebranded as Digital Metal (Courtesy Höganäs)

The full 2012 Höganäs Annual report is available for download from the Höganäs website.

Höganäs reports drop in sales during first quarter

An interim statement issued by Höganäs AB has reported net sales down 13% year on year for the first quarter 2013 (1 January – 31 March) at MSEK 1,577. Gross profit for the period was reported at MSEK 445.

The company stated that demand conditions were worse than the corresponding period of the previous year in most markets, apart from China and South America. Operating income was MSEK 250, and income after tax was MSEK 186. Lower sales volumes had a negative impact on income, while savings measures and a continued focus on cost efficiency had a positive effect. Operating margin was 15.9% (15.6).

www.hoganas.com

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GKN sales up 9% in Q1 2013, receives recognition from customers

Sales at GKN for the three months ended March 31 2013 totalled £1,891 million, a 9% increase over the comparable period in 2012 (£1,742 million).

Trading profit reduced slightly to £139 million, and included a £23 million charge for restructuring and a £19 million contribution from acquisitions. Trading margin was 7.4%, or 8.6% excluding the restructuring charges. Profit before taxation was £119 million, a 4% reduction over the comparable period in 2012.

Nigel Stein, Chief Executive, GKN plc, stated, "We have met our expectations for the first quarter against the backdrop of challenging end markets. Last year's acquisition, GKN Aerospace Engine Systems (formerly Volvo Aero), is performing well against our restructuring and integration plan and made a strong financial contribution. With restructuring charges now largely behind us, we expect the remainder of the year to show improvement, supported by our market leadership positions, advanced technology and extensive global footprint."

GKN Powder Metallurgy's first quarter 2013 sales were broadly flat at £235 million. After including restructuring charges of £4 million, trading profit was £20 million. Trading margin was 8.5%, or 10.2% excluding restructuring. In 2012 the division reported sales of £874 million for the year, with profit of £87 million and a trading margin of 10%.

GKN achieves Bosch Preferred Supplier Status

GKN Sinter Metals received Bosch's preferred supplier status, on behalf of GKN plc, for the third consecutive year, a clear sign, stated GKN, of the strength of the Group's relationship with Bosch.

Herbert Rainer (right) Bosch Key Account GKN Sinter Metals accepts the certificate from Ruben Holste (left) Bosch Purchasing Automotive Business

Bosch assigns this status to suppliers with a continually outstanding performance level, based on four main criteria; quality, costs, reliability and innovation drive.

GKN and Bosch have shared a close business relationship that goes back over 40 years and have worked together on a large number of engineering and development projects. Since 1995, GKN Sinter Metals has provided sintered parts to Bosch, serving all business areas. The product range covers automotive, industrial and consumer applications supplied from GKN Sinter Metals plants all over the world, including brake components, steering system components, hydraulic components and sinter bearings.

Primarily GKN Sinter Metals focused on providing conventional sintered components for Bosch, however it is now utilising the broader technology scope that GKN Sinter Metals offers, from engine components made by Metal Injection Moulding (MIM) to porous metal filter parts for the chemical industry.

Roland Pahl, Vice President Sales & Marketing, Europe and Asia Pacific, stated, "We are delighted about the trust that Bosch, as one of our global key customers, has placed in our engineering skills, production plants and technical capabilities. This is another milestone on our long-term partnership and we look forward to working with Bosch in the future."

Ford Q1 certification for GKN Sinter Metals

GKN Sinter Metals also announced that its plant based in Milan, Italy, was awarded Ford's prestigious Q1 certification for supplier excellence.

The Q1 award indicates that a supplier's facility is identified as a preferred supplier to the Ford Motor Company and recognises excellence in four areas: capable systems, continuous improvement, ongoing performance and customer satisfaction.

"We are very proud to have received this award which recognises the continued focus of GKN Sinter Metals on serving its customers and will present exciting new opportunities in the future. We are looking forward to continuing to develop our relationship with Ford," stated Gianni Ronchi, Plant Manager.

Ford is GKN Sinter Metals' largest customer as well as being the third largest customer to the whole GKN group. GKN Sinter Metals supplies Ford with conventional PM components that are predominantly integrated into transmission and engine systems.

www.gkn.com

Next generation takes charge at Austria's Miba AG

Miba AG, headquartered in Laakirchen, Austria, has announced key changes to its Management Board. As of July 1, 2013, Chairman of the Management Board Peter Mitterbauer (70) will resign from the Management Board and will pass on the chairmanship to his son, F. Peter Mitterbauer (37).

This will be the third generation of the Mitterbauer family to take the helm since the company was established in 1927.

"Now, at the age of 70, the right moment for this change has come. We have prepared a long time for this, and I have absolute confidence in the new and top-class Management Board team," stated Peter Mitterbauer.

F. Peter Mitterbauer studied engineering economics and mechanical engineering at the Vienna University of Technology and graduated from the MBA program Insead in Fontainebleau and in Singapore. After gathering five years of solid experience at other international companies he joined Miba in 2006.

F Peter Mitterbauer will take over the position of Chairman of the Management Board from his father (Courtesy Miba)

Following a year long deployment at the Miba site in China (Suzhou) and serving as Managing Director Sales & Marketing for three years in the Friction Group, F. Peter Mitterbauer has held responsibility on the Management Board for the friction business since 2011, as CEO of the Friction Group.

"The business that my grandfather established and that my father consistently expanded over the last decades is truly remarkable. It is a great challenge and a unique responsibility to continue this success and to advance the development of our company for the next generation," stated F Peter Mitterbauer.

Also effective from July 1 2013, Markus Hofer (41), Vice President Corporate Finance since October 2011, will be appointed Chief Financial Officer. On the Management Board of Miba AG, he will assume full responsibility for Corporate Finance, IT, Business Excellence, and the Internal Control System.

Board Member Norbert Schrüfer will depart from the Management Board of Miba AG when his contract expires on January 31 2013, concurrently with the planned size reduction of this corporate body. He remains CEO of the New Technologies Group and will serve as Vice President Innovation & Technology.

The restructured Management Board team of Miba AG (left to right) F Peter Mitterbauer, Wolfgang Litzlbauer, Harald Neubert, Markus Hofer (Courtesy Miba)

As of July 1 2013, Miba AG will be headed by a four-member Management Board, composed as follows:

- F. Peter Mitterbauer: Chairman of the Management Board, responsible for the New Technologies Group and Strategy; Human Capital; Controlling; Technology & Innovation; Communications
- Wolfgang Litzlbauer: Vice Chairman, responsible for the Bearing, Friction and Coating Groups; Purchasing
- Harald Neubert: responsible for the Sinter Group; Quality
- Markus Hofer: Chief Financial Officer responsible for Corporate Finance; IT; Business Excellence; Internal Control System.

www.miba.com

Japan's PM industry makes gains in 2012

Japan's ferrous PM industry reported a 3.6% gain in production in 2012 to reach 96,979 mt, whilst copper-based PM products showed a more substantial gain to 4,427 mt from 3,567 mt in 2011. The combined total of 101,406 mt amounted to a 4.4% gain over 2011.

The Japan Powder Metallurgy Association (JPMA) reports that production value for structural PM parts also rose slightly in 2012 but was still substantially below the peak reached in 2007 (Fig. 1).

Around 92% of all structural PM parts produced by Japan's 63 PM producers find applications in the automotive sector with the average Japanese car containing 9.2 kg of PM parts in 2011.

PM self-lubricating bearing production in Japan was relatively flat in 2012 reports the JPMA. The breakdown of PM parts and PM bearings applications in vehicles in 2011 is shown in Fig. 2

www.jpma.gr.jp

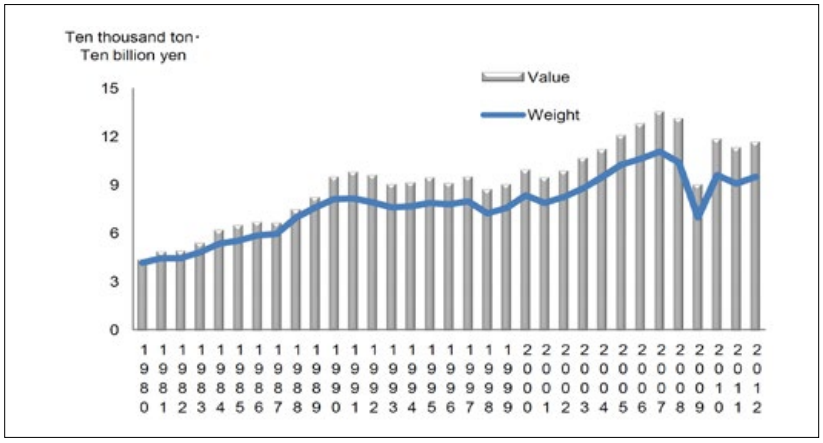


Fig. 1 Production trend of structural PM parts in Japan (source: JPMA)

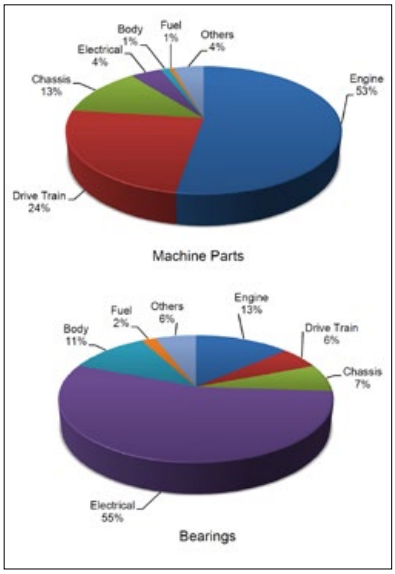


Fig. 2 Breakdown of structural PM parts and PM bearings applications in automobiles in Japan - top: structural parts, bottom: PM bearings (source: JPMA)

Japan's cemented carbide production drops in 2012

Following three years of growth in 2009-2011 Japan's cemented carbide (hardmetal) industry saw a 5.3% fall in production in 2012, mainly as a result of a sharp drop in output in the final quarter of the year.

The Japan Cemented Carbide Tool Manufacturers Association reported that 5580 tonnes of cemented carbide had been produced in 2012 of which around 75% was for tungsten carbide based cutting tools, 12.7% WC wear parts, 2.8% mining and civil engineering tools, and others around 8%.

Total value of cemented carbide production in Japan in 2012 was reported as Yen287,285 billion ($3.122 billion), which is down 1.4% on the corresponding value in 2011.

www.jctma.jp

Chinese PM production stalls in 2012

Despite the continuing strength of the automotive market in China in 2012, which saw total vehicle production rise by 4.3% to 19.3 million vehicles, the Chinese Powder Metallurgy market appears to have stalled according to preliminary figures submitted by a core group of 53 members of the China Machine Powder Metallurgy Association (CMPMA).

Total production tonnage for the 53 reporting PM enterprises was stated to be 161,144 tonnes, which is level with the 2011 figure, whilst sales were also flat at Yuan 5.420 billion ($878.7 million).

The CMPMA reported that there were falls in total profits from Yuan 636 million ($101 million) reported for 2011 to Yuan 478 million ($77 million) in 2012. There was also a fall in the production of new PM products year-on-year to Yuan 725 million. 11.5% of PM production was exported in 2012, an increase of 9.8% year-on-year.

Initial figures published, referring to 34 reporting members, stated that just over 58% of Chinese ferrous PM parts find applications in the automotive sector (47.1% vehicles and 11.2% motor cycles), up from 56% in 2011. However, the 12.5% fall in production of motor cycles to 23.6 million in 2012 is said to have impacted negatively on PM shipments to this sector. Some 23.8% of PM parts went to the appliance sector, 5.7% for power tools, 3.4% construction machinery, 2.3% agricultural machinery and others at 6.5%.

Sintered self-lubricating bearings saw a decline in production in China in 2012, down 13.3% year-on-year to 12,751 mt. Of this total, 71% comprised ferrous based PM bearings with copper-based bearings the remainder. Copper-based structural parts made up just 1.5% of total PM production in China.

Metaldyne receives three GM Supplier Quality Awards

Metaldyne, LLC has announced that in total three of its global operating plants received Supplier Quality Excellence Awards from General Motors for exceptional quality and delivery performance in 2012.

General Motors recognised Metaldyne facilities located in Ramos Arizpe, Mexico, Suzhou, China and North Vernon, Indiana, USA, for quality performance over the past 12 months. Plants must meet a set of stringent quality and delivery performance grading criteria to be eligible for the award, which is only given to a select group of GM's top performing suppliers.

"These awards are a testament to Metaldyne's operating model, which is based upon a commitment to operational excellence across our global facilities," stated Thomas Amato, President and CEO, Metaldyne. "It is an honour to be recognised by General Motors for the efforts of our dedicated employees at these facilities."

Metaldyne supplies GM with fully machined powder forged connecting rods

Metaldyne has over $1 billion in annual revenue, with 25 locations in 13 countries, and is owned by American Securities, a leading private equity firm. General Motors is one of Metaldyne's largest customers.

www.metaldyne.com

Global vehicle production reaches over 84 million in 2012

World vehicle production reached 84.1 million vehicles in 2012, stated Patrick Blain, President of OICA. This record level is up by more than 5% compared to 2011.

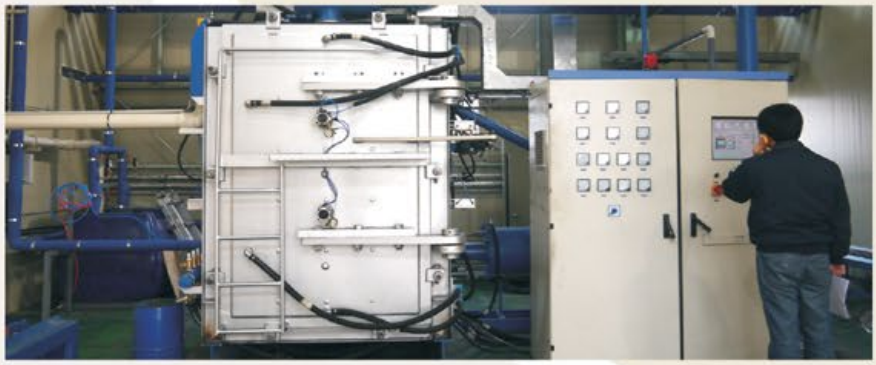
World vehicle sales were estimated at almost 82 million in 2012. Production figures, stated Blain, never match sales because of many non-recorded registrations in many countries (vehicles for administration, military, embassies, etc) and vehicles in short term inventory soon to be registered.

"After a dramatic fall in 2009 to 61.8 million units due to the 2008 crisis, the world vehicles production has clearly recovered globally," stated Blain. "Asia maintained its leadership, with a total production reaching 43.7 million units in 2012, followed by the Americas at 20 million, and Europe trailing with a figure of less than 20 million."

www.oica.net

DIYUAN METALLURGY FURNACE

We are concentrating on Furnaces for Cemented Carbides.



- Large Scale Zinc Furnace for Reclaimation of Cemented Carbide

- Gas Pressure Sintering Furnace(HIP)

- Automatic High Temperature Graphite Heating Pusher Furnace (2200℃)

- Rotary Furnace
- Pusher Type Reduction Furnace
- Carbon Tube Furnace for carbonization
- Automatic High Temperature Graphite Heating Pusher Furnace for carbonization
- Dewaxing Furnace
- High Vacuum Metal sheet Furnace
- Dewaxing & sintering Furnace with Multi-gases Controlled
- Lab Furnace for Measuring the Content of Carbon in Carbides.
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- High Temperature Hardness Tester

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Person to contact: Mr. Lu guopu
Mobile phone: +86 13307418206
E-mail:sales@diyuanmf.com

www.diyuanmf.com

Address: Zhuzhou Diyuan Powder Metallurgy Furnace Co.,Ltd
Jinshan Industrial Zone, Hetang District, Zhuzhou City,HunanProvince,China

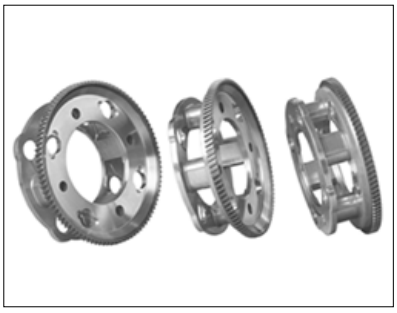
Fully automated Powder Metallurgy planetary carrier production line opened at PMG

PMG Holding, a leading global supplier of sintered components and systems for the automotive industry, has completed a €9 million investment with the opening of a new, fully automated sintered planetary carrier production line at PMG's plant in Füssen, Germany.

The inauguration of the new PM production line, which has the capacity to produce around 700,000 PM planetary carriers annually for use in automatic gearboxes, took place on March 12, 2013.

PMG's state of the art production line to produce PM planetary carriers for automatic transmissions

In attendance during the opening were members of the PMG Management Team, local representatives, customers and other business partners, including Karl Theo Goldschmidt, who represented the family which recently took over the PMG business.



Planetary carriers will be manufactured at the new PMG Füssen facility

"We celebrate a further milestone for the PMG group, as well as the successful implemented first step of the comprehensive expansion and automation strategy for our plant in Füssen," stated Dr Krehl, CEO of PMG Holding.

PMG has six plants in four countries (Germany, Spain, USA, China) employing around 1250 people with annual turnover in the region of €210 million.

www.pmgsinter.com

Strong 2012 results reported at Hilti Group

The Hilti Group, headquartered in Schaan, Liechtenstein, has reported strong financial results for 2012. On the basis of 5.2% sales growth in 2012, the Hilti Group was able to substantially improve its operating result (+45%) and net income (+101%). This growth was due in large measure to the rapid implementation of the profitability enhancement program launched in 2011, stated the company.

"The economic environment around the globe was extremely challenging in 2012. While relevant southern European markets continued to contract, the Hilti Group was able to profit from solid economic momentum in South and North America as well as Asia. Sales increased by 5.2% on the previous year to CHF 4,204 million and sales growth in local currencies amounted to 4.4%."

Double-digit growth rates were achieved in North America (+13.4% in local currencies) and Latin America (+32.4%) but the Hilti Group could not evade the continued severe economic downturn in southern Europe, primarily in major markets like Italy and Spain, and this ultimately caused sales to drop slightly in Europe as a whole (-1.9%). Predominantly positive market momentum in the Asia/Pacific and Eastern Europe / Middle East / Africa regions translated into correspondingly high growth rates of 9.5 and 8.9%, respectively.

The Hilti Group implemented the cost-saving measures introduced at Hilti Corporate Headquarters at the end of 2011 and improved productivity at all stages of the Group's value chain according to plan in 2012. The operating result improved substantially from CHF 207 million to CHF 301 million (+45%), while net income doubled from CHF 97 million to CHF 194 million (+101%).

Despite 4.4% sales growth in local currencies, it was possible to further decrease net working capital and, in line with significantly higher profitability, cash flow from operating activities reached a record CHF 617 million, corresponding to an increase of CHF 375 million (+155%). Return on capital employed (ROCE) improved from 6.5 to 9.5% due to the aforementioned measures.

Investments in research and development were, at CHF 175 million, largely at the same level with those of the previous year. The number of staff was reduced slightly (-3%) from 21,848 to 21,139 as a result of structural corrections at Corporate Headquarters as well as in southern Europe and other individual markets.

"Despite challenging conditions, 2012 was a successful year for us. We returned satisfactory sales results, improved our cash flow substantially, and achieved very solid profit growth", stated CEO Bo Risberg. "We still have some way to go to achieve our profitability goals, so we shall continue to implement the profitability enhancement and capital efficiency measures consistently."

www.hilti.com

ALD acquires nitriding technology for advanced wear resistance

ALD Vacuum Technologies GmbH has acquired a patented wear and corrosion resistance nitriding technology that utilises an Active Screen Plasma Nitriding process (ASPN).

The ASPN technology modifies a component's surface by adding nitrogen, using plasma technologies, to create a specific nitride layer. This modification improves the mechanical strength, corrosion resistance, and electrical conductivity of materials.

ASPN enables the nitriding process to occur in low temperatures and for non-conductive materials, which is not possible with any other technology commercially available today.

The ability to apply the ASPN technology at low temperatures is the key element that significantly broadens the market for this surface treatment.

www.amg-nv.com

Rare earth magnets to be recycled in new EU research project

In response to the supply restrictions of rare earth metals, critical in many modern electronics, an international consortium has been brought together to identify new solutions to help with the demand from European industry.

One of the consortiums aims is to dramatically increase the amount of rare earth materials recovered and remanufactured from existing waste streams. The project brings together European industry and academia across the supply chain to develop the innovative technologies, business models and market information required to exploit this valuable resource reducing dependence on primary sources.

The partners will develop new and innovative processes for the recovery and recycling of neodymium iron boron magnets (NdFeB) from a range of waste electronic and electrical equipment (WEEE). Advanced sensing and mechanical separation techniques will be developed in combination with innovative processes to recover the rare earth magnets in the WEEE.

Significantly, the aim will be to recover material in a form that can easily re-enter the primary magnet manufacturing production route, so providing large energy savings and reduced production costs for European manufacturers.

The project, named Remanence, brings together Europe's leading experts in sensing, disassembly, recycling technology and materials processing in a multi-disciplinary project able to deliver significant technical advances. C-Tech Innovation Ltd will lead the consortium, which also includes The University of Birmingham, Stena Technoworld AB, ACREO Swedish ICT AB, Leitat Technological Centre, OptiSort AB, Chalmers Industriteknik, Magneti Ljubljana and Kolektor Magnet Technology GmbH.

Remanence is funded by FP7, the Seventh European Framework Programme for research and technological development, and is expected to run until mid 2016.

NTN develops new sintered iron bearing with copper layer to replace bronze bearings

Japanese bearing manufacturer NTN Corporation has announced the development of a new bearing material with similar or improved sliding performance to that of bronze sintered bearings. The new bearing incorporates a copper layer on the surface, formed by adding a small quantity of a unique copper powder to sintered iron.

Sintered bearings are generally widely used in automobiles and office equipment, with the bearing material categorized as iron-based or bronze-based. Applications that require bearings with a high level of sliding performance, including automotive electrical components such as power window and fan motors, or photo-copiers or laser printers, are made of bronze materials.

With the increase in the price of copper in recent years, there has been greater demand for sintered bearings made of materials that can be used as a substitute for bronze bearings. NTN's newly developed "BEARPHITE CL" is an iron-based sintered bearing with a small quantity of unique copper powder, and special material composition to form a specially designed copper layer on the bearing surface.

Being an iron-based bearing, the new bearing has a higher material strength than bronze bearings, as well as outstanding wear-resistance.

NTN states that is has begun offering the bearing to manufacturers of automobile electrical components and office equipment, and aims to market the bearing extensively in the automotive and industrial sectors.

www.ntn.com

Features compared to conventional bearings		
	Compared to bronze bearings	**Compared to copper-iron bearings**
(1) Torque (sliding performance) Developed product: coefficient of friction 0.1 or less	Same or better	20% or lower torque
(2) Wear-resistance	2-times or higher	1.5-times or higher
(3) Radial crushing strength	1.2-times or higher	1.1-times or higher

Soft magnetic powders play key role in Stirling Engine for power generation

Microgen's Stirling Engine

Microgen Engine Corp., based in Peterborough, UK, has developed a piston-free Stirling Engine for its "microCHP" (Combined Heat and Power) appliance which incorporates inner stators made from Somaloy soft magnetic composite powder produced by Höganäs AB, Sweden.

The microCHP appliance produces 1 kW of electrical power which can be used to run household appliances as well as providing heating and hot water.

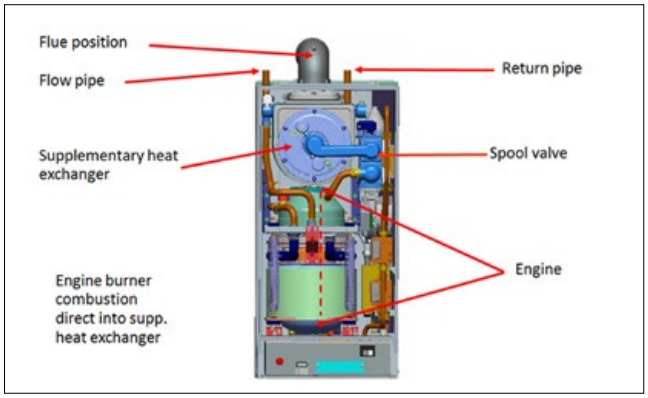
Unlike most Stirling engines which are kinetic with a crankshaft and rotary motion, the Microgen Engine version has a piston-free linear motion and thus is not subject to wear and needs no lubrication.

The first piston-free Stirling engines have been incorporated into wall mounted, high efficiency boilers for domestic heating.

By using Somaloy powder in its stator, Microgen was able to improve the production of its Stirling Engine significantly. If laminated steel would have been used for the stator it would have required the production of a laminated stack of 500 sheets with very fine dimensional limits. The Somaloy stator required the compaction of only one part.

The operation of the microCHP appliance can be seen on the company's website

www.microgen-engine.com



The microCHP appliance can produce approximately 1kW

New European Additive Manufacturing Group formed

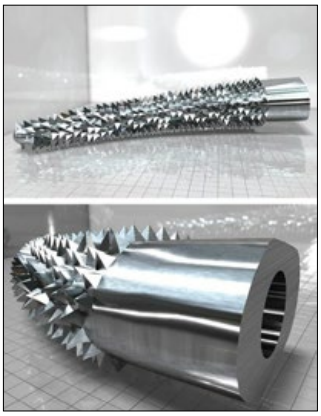
Following discussions between members of the European Powder Metallurgy Association (EPMA) who are active across the Additive Manufacturing (AM) supply chain, it has been formally agreed that the EPMA will launch a new sectoral group. To be called the European Additive Manufacturing Group (EAMG) its objectives will be fourfold:

- To increase the awareness of the Additive Manufacturing technology, with a special focus on metal powder based products.
- To enable the benefits of joint action, for example through research programmes, workshops, benchmarking and exchange of knowledge.
- To improve the understanding of the benefits of metal based AM technology by end users, designers, mechanical engineers, metallurgists and students.
- To assist in the development of International standards for the AM Sector.

There will be two co-chairmen of the group, Ralf Carlström of Höganäs AB Sweden and Claus Aumund-Kopp from Fraunhofer IFAM, Germany. They will coordinate activities in several areas including Conferences & Workshops, Promotion Activities, Technical Research Programs, Training and Standardisation work.

www.epma.com

Within Technologies produces titanium medical parts using Additive Manufacturing



The recent MD&M West exhibition held in Anaheim, California, USA, highlighted further developments in the use of Additive Manufacturing (AM) in the production of complex 3D components for medical applications, states a report in *Design News*.

Within Technologies, a design consultancy based in London, UK, showed how the boundaries of Additive Manufacturing could be broadened in medical applications with a titanium bone rasp for hollowing out femurs before inserting an implant.

The custom-designed Ti bone rasp is made using EOS laser sintering technology with titanium alloy powder. Within Technologies has also optimised the design and lattice structure/surface skin of an acetabular cup to allow speedy integration with the patient's bone.

Other Ti devices developed by Within using laser sintering include spinal and finger implants.

www.withinlab.com

Arcam launches new EBM system for industrial production of orthopaedic implants

Arcam AB has announced the introduction of a new electron beam melting (EBM) machine designed specifically for the Additive Manufacturing of orthopaedic implants.

The new Arcam Q10 has been developed in close collaboration with leading medical implant manufacturers and is designed to meet the implant industry's need for ease of use, productivity, accuracy and quality assurance. Arcam Q10 replaces the company's Arcam A1.

The orthopaedic market is one of Arcam's two main markets, the other being the aerospace industry.

EBM technology has been used for implant production since 2007, and more than 30,000 EBM manufactured orthopaedic devices have been implanted worldwide. The market share of EBM manufactured implants is growing steadily.

The Arcam Q10 includes several new features for industrial volume production, including increased productivity, higher resolution, and Arcam LayerQam™, a new camera based monitoring system for continuous quality assurance.

www.arcam.com

Custom prosthesis designed and 3D printed for disabled climber

A disabled mountaineering enthusiast from California, USA has received a new titanium alloy prosthesis designed especially to help with climbing.

The lower-leg amputee, a keen climber, found the specialised shoes difficult to use. They fitted poorly with the generic shape of his standard artificial foot and tended to wear out quickly. His climbing partner, a former mechanical engineer at a major aerospace company in the US, used a CAD package on her laptop to design an aggressive climbing prosthesis with a downturned toe, eliminating the need to use a shoe.

Amputee C J Howard climbing with his prosthetic foot in South Lake Tahoe, California

The foot was made from Ti64 titanium alloy powder using an EOS direct metal laser sintering (DMLS) machine at Morris Technologies in Ohio, USA.

Fabricating the approximately 150 x 75 x 50 mm, smooth-edged foot took about 40 hours. The finished 2.25 kg prosthetic was a single-piece construction, of high strength and stiffness, hollow to minimise weight and with no seams or fasteners. It was stress relieved to cure the metal and ensure material strength.

To create the combined foot and shoe, it was coated with a rubber used for the soles of climbing shoes. The artificial leg, a solid titanium rod, connects to a socket on the prosthesis.

The prosthetic all-in-one climbing foot fitted to its artificial titanium leg

While the prosthesis was the first that Morris Technologies hd produced, Tim Warden, vice president of sales and marketing, regards laser sintering as ideal for this kind of application. "A prosthesis should ideally be customised to an individual's anatomy. After he or she has tried it out, if it doesn't fit or function quite correctly, we can tweak the CAD file and re-grow the product, adding a little more material in a critical area, for example," stated Warden.

www.morristech.com
www.eos.info

CSIRO using titanium Additive Manufacturing to track big fish

The latest fish tag design manufactured from titanium using Additive Manufacturing

The Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia's national science agency, has been using Additive Manufacturing technology to create tagging devices to track large fish such as marlin, tuna, swordfish, trevally and sharks.

CSIRO is manufacturing the tags from titanium at its 3D printing facility, Lab 22, in Melbourne. The tags are created overnight and then shipped to Tasmania where marine scientists are trialling them.

One of the advantages of the process is that it enables rapid manufacture of multiple design variations which can then be tested simultaneously. "Using our Arcam 3D printing machine, we've been able to re-design and make a series of modified tags within a week," stated John Barnes, who leads CSIRO's research in titanium technologies.

"When our marine science colleagues asked us to help build a better fish tag, we were able to send them new prototypes before their next trip to sea," added Barnes.

Tags are made of titanium for several reasons: the metal is strong, resists the salty corrosiveness of the marine environment, and is biocompatible (non-toxic to living tissues).

Had the scientists been using conventional tags which are machined out of metal blocks, it would have taken a couple of months to design, manufacture and receive the new designs for testing.

"Our early trials showed that the textured surface worked well in improving retention of the tag, but we need to fine-tune the design of the tag tip to make sure that it pierces the fish skin as easily as possible," continued Barnes.

"The fast turnaround speeds up the design process – it's very easy to incorporate amendments to designs. 3D printing enables very fast testing of new product designs, which why it's so attractive to manufacturers wanting to trial new products."

Scientists from a number of agencies, including CSIRO Marine and Atmospheric Research, use fish tags to track movements of individual marine species and increase understanding of their behaviour.

Medical implants such as dental implants and hip joints are made of biocompatible titanium with a surface texturing which speeds healing and tissue attachment after implantation. Scientists hope that a similar rough surface will help the tag to stay in fish longer.

"A streamlined tag that easily penetrates the fish's skin, but has improved longevity because it integrates with muscle and cartilage, would be of great interest to our colleagues conducting tagging programs across the world," stated Russell Bradford, a CSIRO marine researcher.

CSIRO's Lab 22 3D printing facility was established in October 2012 and has been used to manufacture a range of prototype products including biomedical implants, automotive, chemical processing and aerospace parts.

www.csiro.au

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 laborious and time-consuming.

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.

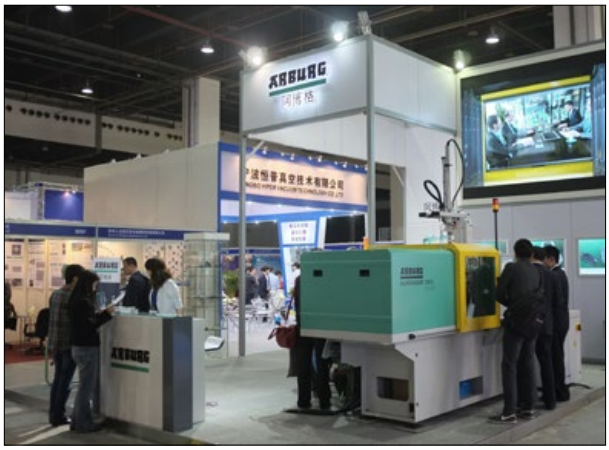
www.eos.info

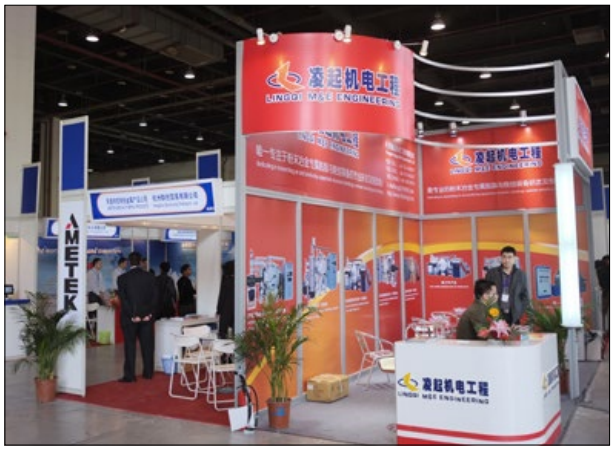
Gallery: PM CHINA 2013 exhibition attracts record visitors

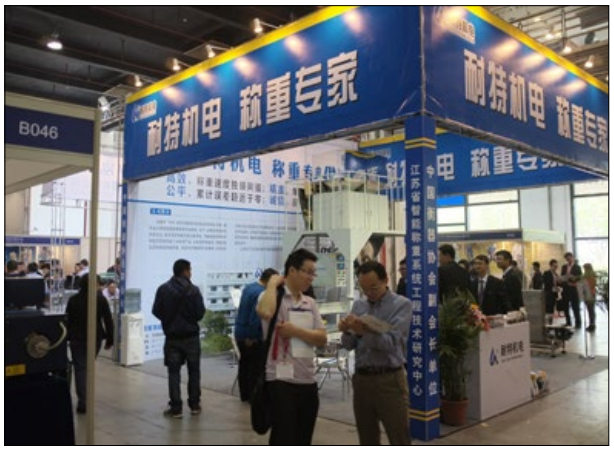
The 2013 China (Shanghai) International Power Metallurgy Exhibition & Conference took place from April 26-28 at the Everbright Convention Centre in Shanghai, China. Now in its 6th year, the 2013 exhibition proved to be significantly larger than the previous event in 2012 and attracted a large number of exhibition visitors from throughout China and further afield.

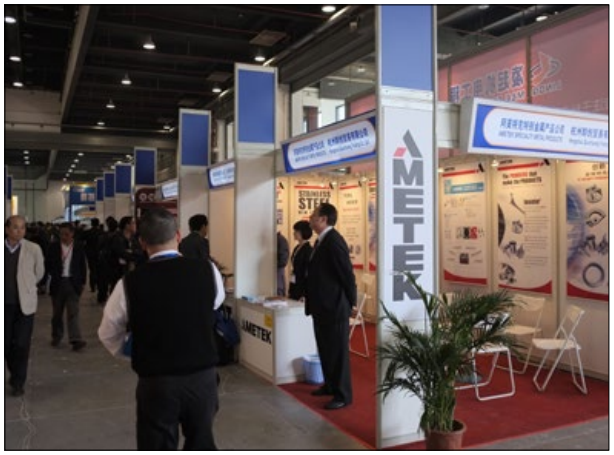
Inovar Communications Ltd exhibited at the event with its publications *Powder Metallurgy Review* and *Powder Injection Moulding International*. Jon Craxford, Advertising Sales Director, stated, "The volume and quality of visitors at this year's show was outstanding and by the end of the second day of the exhibition more than 1500 copies of our publications had been collected from our stand. As the only international publications for PM and PIM to be present at this important event we were delighted with the levels of interest in both our print and on-line products."

www.ipmd.net/pmreview
www.pim-international.com









New retrofit press control unit from Cieco Inc

Cieco Inc, based in Clinton, PA, USA, has announced the development of a new microprocessor control unit to replace obsolete controls in older presses. The new Automator II unit is suitable for almost any compacting press and will bring them into current ANSI safety standards, B11.1 and B11.16 (MP-47) with the safety clutch/brake control module.

The Automator II offers up to 48 safety sensor inputs, almost twice as many as previously available. Whenever a sensor fault occurs, a detailed fault message is displayed to enable the operator to focus their effort on trouble shooting the die rather than looking for the faulted sensor. The faults are then time stamped and put into a history file.

The control features a new 15" colour touch screen for operational functions such as programmable limit switches, tonnage monitor w/graphics, multi-axis control (ram adjust, fill, etc), ball screw shoe feed, Ethernet, job storage, back up w/USB, etc. The unit lets users store any type of information including press schematics, part and machine drawings, maintenance records, photographs and installation manuals of your auxiliary equipment. The Automator II is available for installation by the company's field service technicians.

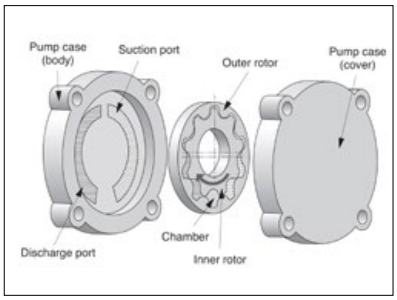
The new Automator II control unit from Cieco Inc

www.ciecocontrols.com

Sumitomo Electric develops high efficiency oil pump rotors

Sintered internal rotor gears are widely used in oil pumps for engines and transmissions, and Sumitomo Electric of Itami, Japan, is one of the leaders in developing and commercialising sintered rotors featuring proprietary tooth profiles, which improve the efficiency of oil pumps and hence reduce energy losses attributed to the pumps.

Energy losses are said to account for approx. 10% of total engine energy loss in the case of an engine lubrication oil pump which increases to 20-30% for automatic transmissions, and between 5 and 10% for oil pumps used in hybrid vehicles. The typical structure and mechanism of an oil pump with internal sintered inner and outer rotors is shown in the figure, with the outer rotor having one more tooth than the inner one.



The typical structure and mechanism of an oil pump with internal sintered inner and outer rotors

Sumitomo Electric has now added a new 'Geocloid' design of oil pump rotors which the company states allows oil pumps to be downsized to reduce drive torque, but without sacrificing the pump's volumetric efficiency. The new Geocloid motor is 11% smaller in diameter compared with the 'Parachoid' design but has the same discharge volume.

In a report by K. Yoshida, etal, in SEI Technical Review, No.74, 2012, the company reports that it started supplying the new Geocloid oil pump rotors for use in hybrid vehicle transmissions in 2011. Sumitomo Electric is also developing the next generation tooth profile to improve the latest design even further.

www.global-sei.com

HIP 2014 - 11th International HIP Conference Call for Papers

Organisers of HIP 2014, the 11th International Conference on Hot Isostatic Pressing, Stockholm, Sweden, June 9 -13 2014, have issued a Call for Papers.

The triennial conference, organised by the International HIP Committee (IHC) and Jernkontoret, will focus on trends, developments and innovations in the field of hot isostatic pressing (HIP) technology and will cover topics such as material development, production of near net shape (NNS) components, part design and process modelling. Aspects related to Powder Metallurgy processing, diffusion bonding and part densification will also be included.

Deadline for the submission of abstracts is July 3 2013, authors will be notified of acceptance by October 1 2013. Submission of abstracts is only possible online via the event website and should be written in English.

www.hip14.se

International Titanium Conference Call for Papers

Organisers of the International Titanium Powder Processing, Consolidation and Metallurgy Conference, taking place December 2-4 2013 in Hamilton, New Zealand, have issued a Call for Papers.

Taking place at the Titanium Industry Development Association (TiDA) in New Zealand, the conference will focus on Ti Powder and processing, consolidation processes, alloy development and applications.

The event will promote new initiatives within the industry and enable many international networking opportunities. The program will feature international keynote presentations from leading Titanium Powder research facilities, academics and leaders in the manufacturing processes.

www.tida.co.nz

ipmd.net

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Hot Isostatic Pressing (HIP) of large PM products: An industry poised for growth

Hot Isostatic Pressing enables the production of large Powder Metallurgy products that cannot be manufactured by any other process, and the development of ever larger HIP systems is enabling the manufacture of significantly larger components. Such large scale systems present new opportunities for the industry and in this exclusive report for *Powder Metallurgy Review*, Dr Stephen J Mashl, Z-Met, Inc., USA, outlines the development of HIP systems and considers the potential for large Powder Metallurgy products.

Since the development and commercialisation of the Hot Isostatic Pressing (HIP) process in the 1950s and 1960s, the technology has advanced to the point where it is typically used for one of three purposes, to eliminate porosity in metal castings, to diffusion bond materials, or to consolidate particulate materials to a pore-free state.

In the area of Powder Metallurgy (PM) processing, HIP offers a significant benefit in that it is one of the few PM processes that is capable of producing a pore-free component, thereby offering a level of mechanical properties that can meet or exceed those of a forged alloy. Another significant advantage that HIP has over other PM processes is the ability to produce parts of significant size.

In conventional press-and-sinter Powder Metallurgy processing, inter-particle and particle-die wall friction conspire to limit the size of the part that can be made without the development of unacceptably large density gradients. The absence of a die in HIP PM processing eliminates particle-die wall friction and the hydrostatic nature of the stress developed during HIP allows the production of PM components that are larger than those produced by any other PM processes. The goal of this article is to illustrate the capabilities and potential of HIP PM by examining past accomplishments, recent advances, and pending change in the field of large PM components.

The process: HIP PM fabrication techniques

As in many other fabrication processes, there are multiple routes by which a metal powder can be converted into a large near net shape component. Water atomised ferrous powders, such as that shown in Fig. 1a, display good

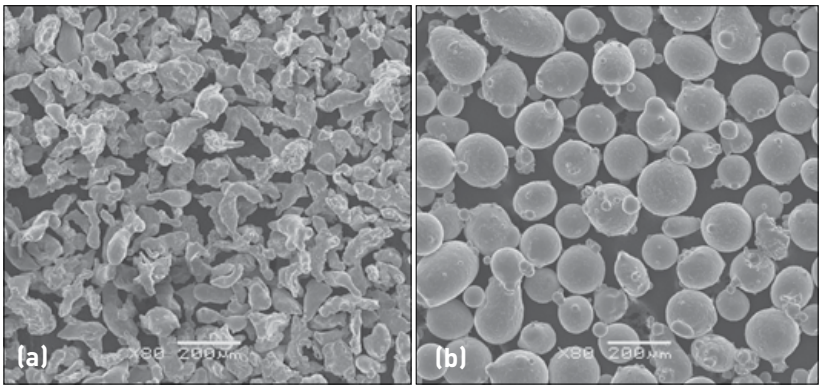

Fig. 1 SEM Images of water atomised (a) and gas atomised (b) 410 stainless steel powder. The irregular shape of the water atomised powder causes it to fill volume less efficiently than a spherical powder however this same characteristic also makes it well suited for cold compaction in a die or via cold isostatic pressing. Spherical powder packs well making it ideal for the production of net- and near-net shapes via the encapsulated HIP route

Fig. 2 A welder closes a seam on a hollow-cylinder HIP can fabricated from sheet metal. The welding process is critical and every inch of weld must be perfect. When the argon atmosphere surrounding the HIP can is pressurised to 100 MPa or more, even a minute leak would allow inert gas to penetrate the porous material within the container, preventing complete densification and relegating the material to the scrap pile [2]

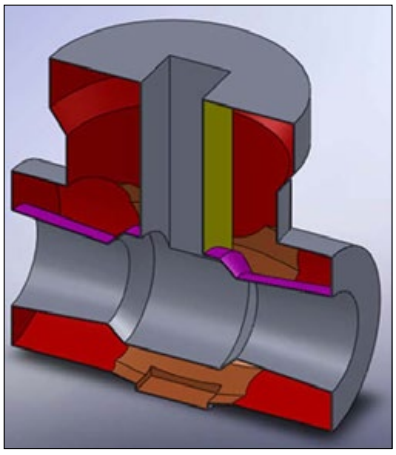

Fig. 3 A CAD Image showing a sectioned sheet metal HIP capsule as it would be fabricated to produce a valve body. The sheet metal exoskeleton is gas-tight, and when filled with loose, spherical powder, acts as the mould that defines the shape of the finished product [3]

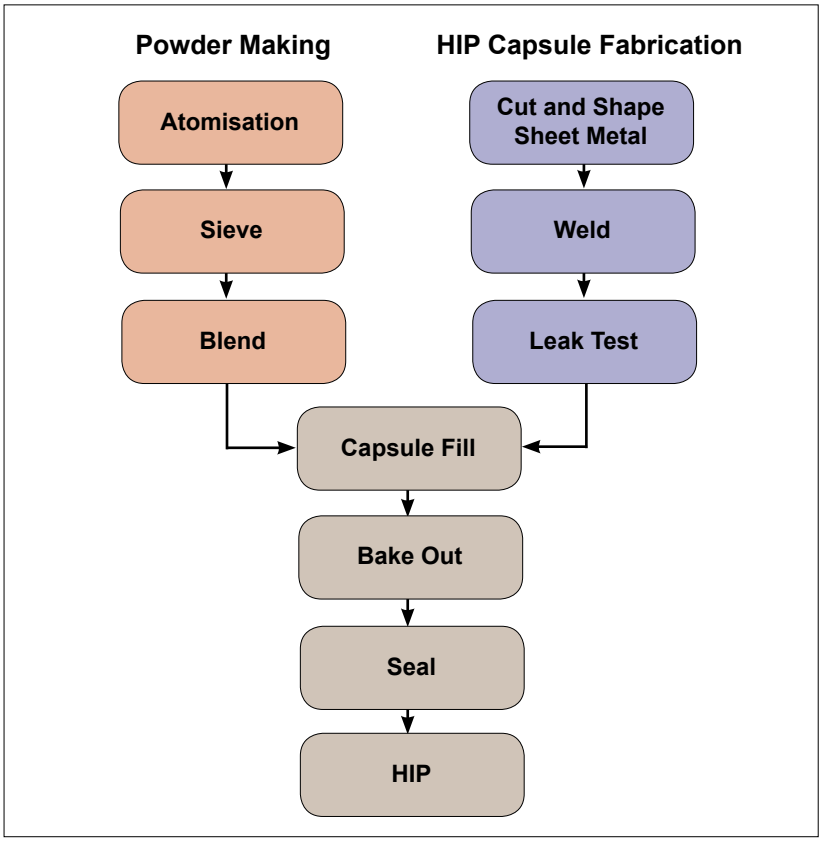

Fig. 4 A flow chart showing the steps involved in manufacturing a HIP PM shaped part. The details associated with each step are often complex and critical to success. The multiple sheet metal pieces that make up a complex HIP can must fit together with precision if one is to make a gas tight container of specific dimensions. The powder must be of high quality and segregation of the powder during handling and capsule filling must be minimised

green strength after cold compaction. A part can be made by pressing the powder into the desired shape at room temperature, sintering that green part in a vacuum or hydrogen environment to a point where remaining porosity has become isolated from the surface, and then simply placing that sintered part into a HIP unit where pressure and temperature act to eliminate the remaining porosity. Because the pores within the part are all sub-surface, there is no need to encapsulate the component in a gas tight container.

Spherical and near-spherical powders such as those in Fig. 1b fill volume relatively efficiently but they cannot be compacted at room temperature. Because of this, spherical powders are typically processed by directly HIPing loose powder within a gas-tight sheet metal container. The sheet metal container, called a HIP can or capsule, can be simple, such as the hollow cylinder being fabricated in Fig. 2, or it can be complex, such as the valve body capsule shown schematically in Fig. 3. Direct HIP of encapsulated metal powders is the predominant method by which large HIP PM shaped products are made [1] thus, that technique will be the focus of this paper.

As illustrated in the flow chart in Fig. 4, the concepts employed to make a HIP PM part are simple: make a container, fill it with powder, evacuate and seal the container, HIP the filled container to convert the powder to a fully dense solid, remove the HIP can, machine, test and ship the finished part to the end user. However, if one is to produce a product that is dimensionally accurate and having optimal mechanical properties, attention to detail during the process is mandatory.

For anything that is not a simple shape, the process starts with capsule design. Discussion between the HIP parts maker and the customer will define the target size and shape of the part after HIP. As-HIPed products are often described as near-net shape implying that some post HIP machining will be needed to produce a finished part. The term "near-net" is relative and how closely the part will match the target finished dimensions is part of the discussion between the customer and the part maker. The characteristics of the powder used, i.e. the packing factor, particle size distribution, etc., and the materials and shape of the HIP capsule will, in part,

Fig. 5 The current "World's Largest HIP" called the Giga-HIP®, this unit is owned and operated by Metal Technology Company, Ltd. (MTC), has a working zone size of 2.05 m in diameter and a height of 4.2 m. Made by Avure Technologies, the unit is capable of processing loads of up to 28 metric tons at temperatures to 1350°C and pressures of 118 MPa

determine the amount of dimensional control that the parts maker has over the as-HIPed product.

The goal of the design engineer in a HIP PM parts making facility is to accurately predict the dimensions and shape of a HIP capsule that, after HIP, will yield a part of the desired size and shape. The commonly used gas atomised powders typically have a packing factor between 0.60 and 0.70, that is, the powder when poured into a container using vibratory fill techniques will achieve a bulk density that is between 60% and 70% of the pore-free density of that material. That means that the overall volume of the filled HIP can will decrease by 30% to 40% as loose powder transforms into a fully dense solid.

While the pressure acting on the exterior of a HIP capsule is equal in all directions, shrinkage of the HIP can is not uniform. Modern CAD software can uniformly expand or shrink a three-dimensional shape but the challenge is to account for non-uniform shrinkage. Multiple factors contribute to non-uniform shrinkage. Corners heat more quickly than flat surfaces resulting in localised variations in the flow stress. The thick sections of a part will influence the movement of material in adjacent thin sections and the capsule itself is a structural entity that is able to resist deformation.

Before the advent of process modelling, a HIP parts designer would rely on empirical information to predict shape change when designing a prototype capsule for a first iteration part. Production of the initial part would show the design engineer where there were inaccuracies in the design, corrections would be made and the revised design would often become the production design. Rarely would a second prototype be made. In many cases, when the part is large and the value of the powder is high, a customer is not willing to sacrifice a part in the pursuit of dimensional accuracy. In those cases, the design engineer increases the size of the capsule to a point where they are certain that the first iteration part will not be undersized. While this approach produces a usable part, it is not an efficient use of material.

The implementation of process simulation tools provide a way to test a preliminary design while both minimising the risk of making an undersized part and providing higher material yields.

HIP process simulation

Computer modelling of industrial metalworking processes has advanced significantly over the last several decades. In fields of metal forging and casting, it is possible to purchase off-the-shelf process modelling software, provide inputs specific to the material used and accurately predict the shape and characteristics of the end product. Process modelling within the HIP PM industry has not yet matured to this degree.

There are currently no commercial, off-the-shelf software packages for HIP PM process simulation. The companies that use a computational predictive tool have likely developed their own simulation programme using published theories on porous plasticity, heat transfer, flow stress, etc. These predictive models can then supplement or replace the empirical approach taken in the past.

One major advantage of 3-D process simulation is that the design engineer can run a simulated HIP cycle using their initial design, evaluate the predicted post-HIP shape, modify the capsule design, and run a second simulation without ever making a physical part. If the process model is accurate and the powder well characterised, this iterative computational procedure can result in an improved capsule design in a short period of time.

Advances in HIP equipment

Large HIP parts cannot be made without large HIP units and advances in both HIP size and technology have facilitated growth in this industry. Advances in furnace design, the implementation of forced convection and improvements in the control of gas movement have advanced temperature uniformity, decreased cycle times and increased cooling rates. While these characteristics can be key to innovation, it is the vessel size that is often of primary importance.

Over the years, the title of "World's Largest HIP Unit" has been claimed by equipment installed in West Jefferson, Ohio; Surahammar, Sweden; Camas, Washington; and now Himeji, Japan. The current, largest, unit operated by Metal Technology Company, Ltd (also known as Kinzoku Giken), shown in

Fig. 6 Inspection of a 10.5 m long suction roll shell used in a pulp paper making facility. During the paper making process, a vacuum is maintained within the interior of the roll while the outer roll is in contact with the wet paper. A roll of this size may be pierced by over one million small, gun-drilled holes allowing the extraction of water. Currently, there is no HIP unit capable of making this part as a single piece [9]

Fig. 7 An inspector examines an as-HIPed cylindrical HIP PM shape used in the construction of the papermaking suction roll shown in Fig. 6. A filled but un-HIPed capsule sits adjacent. The amount of shrinkage occurring during HIP is readily seen by comparing the height of the two pieces [10]

Fig. 5, has a working diameter of just over 2 m with a 4.2 m working height and a load capacity of 28 metric tons. As design engineers around the world begin to take advantage of this and other HIP units we will certainly see parts of record size being produced.

Other large HIP units exist around the world. In 2008, Bodycote installed a new unit in Surahammar, Sweden having a work zone of 1.8 m in diameter by 3.3 m in height. This unit can process material at 104 MPa and 1150°C and is reported to be capable of producing 10,000 tons of HIP PM parts per year [5]. Bodycote also recently announced the addition of a fourth large unit to its North American operations [6].

Past successes

The following three case studies, representing diverse applications from unrelated market segments: papermaking, oil and gas production, and superconducting cryomagnets, illustrate what can be done with HIP PM materials.

The Metso Suction Roll Shell for the Pulp and Paper Industry

During the paper making process, water is removed from the paper sheet by a suction roll such as that shown in Fig. 6. Much of the surface of the hollow cylinder is gun drilled to produce a large array of very small holes. During the papermaking process, the interior is under vacuum while the exterior surface of the roll is in contact with the wet paper sheet. The roll rotates at a speed of 1,000 rpm, is in direct contact with the wet paper, and sees the heaviest load of all of the mill components. The wet environment is also corrosive. Metso switched to a PM alloy in order to achieve both higher strength and improved corrosion resistance [7, 8]. The 10.5 m long roll shown in Fig. 6 is too long to be made in any currently existing HIP unit. To make the part shown, it was necessary to manufacture the roll using three shorter cylindrical sections which were then joined by welding. Fig. 7 shows the HIP PM sections in the pre- and as-HIPed condition.

By switching to a PM alloy, in this case the super-duplex stainless steel, Duplok 27, Metso was able to manufacture a suction roll that possesses improved mechanical

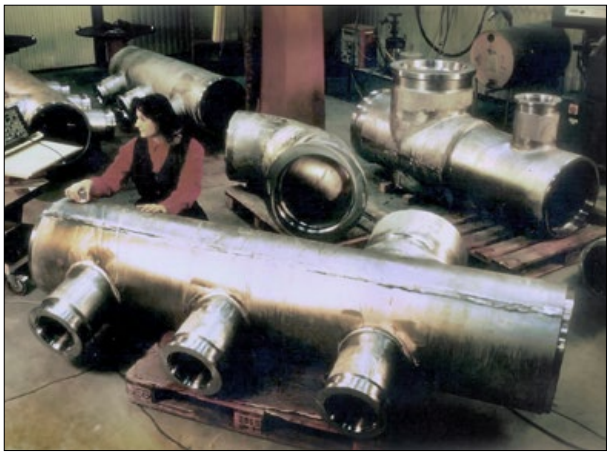

Fig. 8 Surrounded by other pieces of impressive size, a technician ultrasonically inspects a large HIP PM manifold segment. Each segment is a one piece PM part. There are no welds within the individual sections seen here. The high quality of the powder and the homogeneous, equiaxed nature of the HIP PM microstructure make HIP PM materials more transparent to ultrasonic waves than a typical casting or forging. Engineers specify features like wall thicknesses, in part, based upon the minimum detectable defect size. By being able to resolve finer detail in a HIP PM microstructure, the design engineer can reduce wall thickness and still guarantee the part will function in the target application (Courtesy Sandvik)

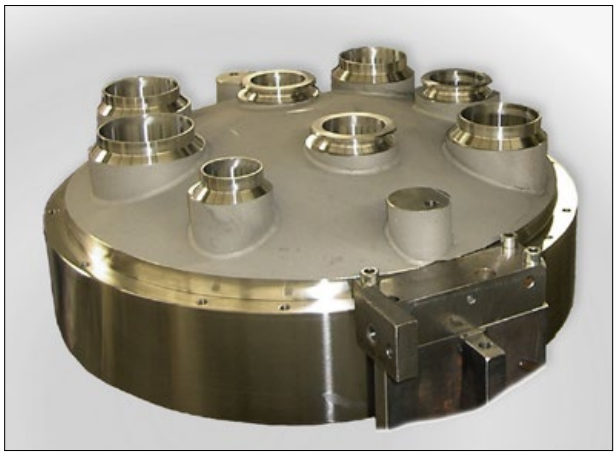

Fig. 9 Image of an award winning 316LN cryomagnet end cover. Over 1200 cryomagnets control the sub-atomic particle beam in the Large Hadron Collider at CERN in Geneva Switzerland. Each cryomagnet has two end covers. While this HIP PM part is not excessively large, the factor that made this part particularly significant and award worthy is that the capsules for this part were assembled using robotic welding and manipulation equipment, resulting in an 8-fold increase in productivity. Over 2700 parts were made (Courtesy MPIF)

properties, allowing the roll to be operated under higher loads and faster roll speeds while also improving the corrosion resistance thereby extending roll service life.

Duplex Stainless Steel Manifold Systems for Oil and Gas Production

The oil and gas industry is a big consumer of HIP PM parts. Swivels, valve bodies and manifold sections, such as those seen in Fig. 8 often weigh in at over 10 metric tons. Closed-die forgings have been the default manufacturing process for this market. In the recent past, limited availability and high demand for large forge capacity resulted in very long lead times presenting an opportunity for HIP PM. Faster delivery combined with excellent mechanical properties and a superior ability to resolve defects during ultrasonic inspection allowed HIP PM to capture some of that market. According to Faisal Akram of Akers Solutions, the forging industry has since added capacity and improved its ability to respond to the oil and gas industry's needs. The lead time for a new forging is said to now be on the order of two to three months, similar to a typical delivery time for a large HIP PM component [11]. The property and non-destructive inspection advantages with HIP PM are still present but the competition for the oil and gas market appears to have increased.

The CERN End Cover – Superconducting Magnetics

Measuring only a little over 600 mm in diameter and weighing approximately 25 Kg, the 316LN stainless steel end cover shown in Fig. 9 is not as massive as the pieces previously discussed yet, in comparison to conventional PM parts, this is a large piece and, in terms of quantities produced and the productivity achieved relative to other HIP PM parts, it was a groundbreaking project.

An excellent example of a collaborative development, this work required contributions by the three parties involved in its manufacture; Carpenter Powder Products, Metso Advanced Materials, and Bodycote HIP. The CERN end cover was selected as the winner of the Powder Metallurgy Design Excellence Grand Prize at PowderMet 2007. The powder composition is shown in Table 1, while a list of the evaluation procedures, properties achieved, and additional comments follow [12].

Part evaluation procedures:

- Optical microscopy of HIPed and heat treated microstructure
- SEM analysis of fracture surface on impact test specimens
- Magnetic permeability
- Conventional tensile testing at room temperature
- Cryogenic tensile testing at 4.2 K
- Charpy impact testing at room temperature and at 4.2 K
- Full penetration TIG and MAG weld testing per EN 288-3
- Characterisation of thermal contraction between room temperature and 4.2 K
- Characterisation of non-metallic inclusions per ASTM E45 and using image analysis according to ASTM E1245.

316LN Chemical Composition									
C	Cr	Ni	Mn	Mo	N	Si	P	S	O
0.017	16.98	13.07	0.71	2.53	0.16	0.59	0.012	0.005	0.011

Table 1 Chemical composition of the 316 LN powder used for the CERN end cover

Properties achieved:

- ASTM E112 Grain Size = 6 to 7
- Magnetic Permeability at room temperature of 1.0027 and 1.0036 (confirming the absence of δ-ferrite and martensite)
- Room temperature yield strength (0.2 offset) = 334 MPa (48,400 psi)
- Room temperature ultimate tensile strength = 664 MPa (96,300 psi)
- Yield Strength at 4.2 Kelvin = 1118 MPa (162,150 psi)
- Ultimate tensile strength at 4.2 Kelvin = 1768 MPa (256,430 psi)
- Impact toughness @ 4.2 Kelvin was a nominal 120 Joules, with no significant directionality (the requirement was for 40 Joules minimum)
- Ductility (Ultimate Strain) = 45%
- Density: pore free.

Comments (comparison of PM to wrought):

Nitrogen enriched, austenitic stainless steel (AISI 316LN) was selected because of its mechanical properties, weldability, and stability of the austenitic phase at low temperatures. The powder producer, Carpenter Powder Products, performed a significant amount of process development to achieve a 316LN powder that would deliver the needed cryogenic impact toughness properties.

The fine grained structure, the absence of residual stresses, isotropic mechanical properties and low frequency of oxides along prior particle boundaries in the HIP PM component resulted in superior mechanical properties and high ductility down to liquid helium temperatures.

A PM component offered significant advantages over alternative manufacturing methods. Closed or open die forging would require significantly more machining, a welded product would need extensive inspection and stress relieving and a cast component would have poorer properties. According to Dr. Stefano Sgobba of CERN, encapsulated HIP PM was the most cost effective route in addition to providing the desired mechanical properties.

Testing indicated that HIPed 316LN possessed superior and isotropic yield and tensile strength when compared to wrought 316LN. This is attributed to the finer grain size of the PM material.

At 4.2 Kelvin, the yield strength of the PM material was slightly lower than a wrought alloy (1118 MPa for PM versus 1198 MPa for wrought).

At 4.2 Kelvin, the UTS of the PM material was slightly higher than wrought (1768 MPa versus 1674 MPa).

The HIP PM 316LN stainless steel possessed a higher ductility, measured as ultimate strain, than wrought (45% versus 38%)

While the impact toughness of this HIP PM stainless steel was lower than that of a typical wrought alloy, the impact properties of samples from this component were ~50% higher than that previously reported for a HIP PM 316LN stainless steel. The improvement in impact toughness (and the reason why HIP PM material did not match wrought toughness was attributed to the presence of micron sized oxide inclusions within the material. The good performance of this particular material is believed to be due to the efforts of Carpenter Powder Products to produce extremely clean (oxide free) powder.

Finally, the HIP PM near net shape was chosen by CERN because it was financially competitive with other processing options.

Market demand

While it is, hopefully, apparent that potential applications for HIP PM parts exist in many and varied markets, traditionally, oil and gas production and power generation have been significant purchasers of HIP PM products. Those markets are addressed here. It is assumed that the factors that influence customer demand in these markets will also be important to consumers from other industries.

Oil and gas

Prior to the economic downturn in 2007-2008, the oil and gas industry was growing and the demand for oil field hardware was very high. Forge shops were running at capacity and stories of one year, or longer, delivery times were heard. When the economy slowed and demand for parts decreased, forging backlogs disappeared and the demand for HIP PM shaped products also slowed.

Recent discussions with members of the oil and gas industry indicated that there continues to be competition between forging and HIP PM [11, 13]. In addition to near-net shape options, high speed machining has also become a factor. An oil and gas customer can purchase a simple preform and machine the billet to shape. Within the spectrum of commercial metals, the stainless steel alloys used in oil and gas are not so highly priced that the loss of some additional material to machining chips is a major concern to the end user.

Subsea oil and gas production is moving to deeper wells requiring operation at higher pressures and under more adverse conditions. As a result of this, minimum property requirements, especially yield strength and fracture toughness specifications are being increased to higher levels. In the immediate future, it appears that the factors that determine which option, shaped forging, HIP PM or machining, continue to be mechanical properties, cost, delivery, dimensional control and service.

Power generation

Perhaps the best recent indicator of market demand for large HIP PM parts in the power generation industry has been the successful efforts of the Electrical Power Research Institute (EPRI) to develop an ASME Code Case for Grade 91 and 316L HIP PM materials. The Electric Power Research Institute, Inc. conducts research, development and demonstration related to the generation, delivery and use of electricity. While they are an independent organisation a large portion of EPRI's funding comes from electric utility companies thus, EPRI's driving of this effort effectively represents "customer pull" for a new technology.

According to Dr. David Gandy at EPRI, Grade 91 alloy is of interest for its application to fossil fuel power generation. The materials in current use have had issues with poor heat treatment and poor welding. The HIP PM approach offers a "more controlled process". The number of welds can be decreased in a HIP PM part decreasing the amount of inspection required and decreasing the probability of failure. Gandy sees potential for HIP PM 316L components to replace castings in nuclear power applications. The castings in current use are very difficult to inspect using ultrasonic techniques, their microstructure and material characteristics rendering them virtually opaque to sound waves. In contrast, the uniform, equiaxed microstructure of a typical HIP PM stainless steel is very "transparent", allowing NDE inspectors to resolve significantly smaller defects in PM alloys.

At the time that this article was written, the final review of the Grade 91 Code Case was complete and that document will be made available when ASME publishes the 2013 code cases next year. The 316L code case draft is currently in the letter ballot stage. Dr Gandy reports that this code case has the backing of NRC and is expected to be approved.

Companies involved in the building of electric power facilities have been able to use HIP PM parts in the past even though no ASME Code Case existed but to do so, an extensive amount of additional testing was necessary. The creation of a code case will greatly facilitate the use of HIP PM materials as a substitute for castings, forgings or welded sub-assemblies. At a HIP session at Euro PM2012 in Basel, Switzerland last year, Dr. Barry Burdett of Rolls Royce expressed concern that the approval of these ASME Code Cases would increase demand for HIP PM parts to a level greater than current global HIP capacity could supply.

Future advances

Even with the Metal Technology Company's GigaHIP® coming on line several years ago, companies that are studying future opportunity report that even a 2 m diameter HIP unit is not sufficiently large for some of the parts that are candidates for HIP PM production. Casual comments made at Euro PM2012 indicated that Avure had performed a study to determine the

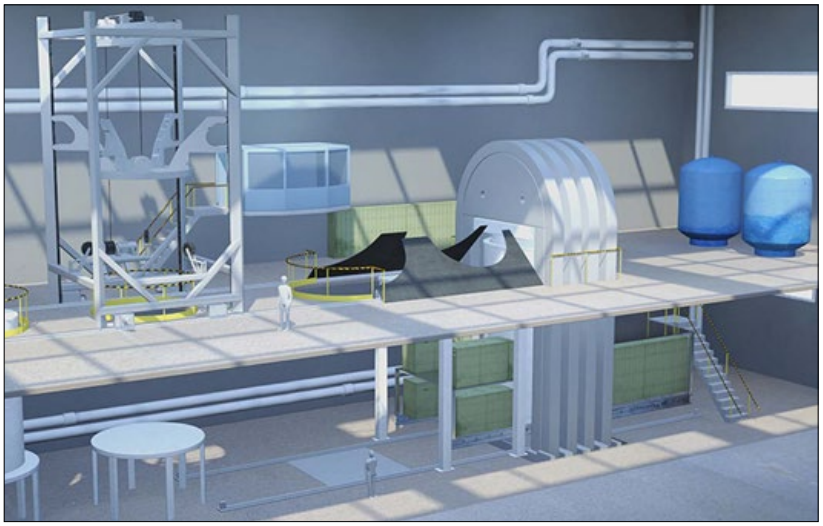

Fig. 10 A 3-D CAD drawing of Avure's new Tera-Pi system

maximum size HIP unit that could be built. The reported result was that a unit having a working diameter of 5 metres could be built using existing technology.

Perhaps in response to this potential demand, at the 2012 PM World Congress in Yokohama, Avure announced the availability of a new TeraPi HIP system. Having a 3.14 m by 5 m working zone and capable of handling a 75 ton load, this system represents a dramatic increase in unit size. Perhaps as important, Avure has also designed the supporting infrastructure for the HIP unit, automating the loading and unloading of the parts as well as furnace and heat shield installation. Fig. 10 shows a CAD rendering of this system.

Conclusion

While the use of HIP PM parts has increased and the business has grown over the last decades, it appears that there is certainly room for improvements that would facilitate growth in the HIP PM industry. Powder continues to be the largest cost in the production of a HIP PM net shape part. Advances in powder making technology that could lead to lower part cost would affect the price of the end product significantly.

The HIP PM industry in general appears to have been slower at adopting technical advances, such as robotics and process simulation, than technologies such as casting or forging. Past conversations with colleagues working in large foundries and forge shops have stated that, while their companies were initially reluctant to spend money on innovation, they were often forced to adopt technological improvements by their largest customers. With the end users in the power generation industry driving the creation of industry codes, it seems possible that these same end users might push for the adoption of advanced manufacturing tools in the future.

Acknowledgements

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Production of complex sintered parts of consistently high quality on cost-effective terms – those are the demands made on modern powder presses. SMS Meer has played a leading role in the further development of the press technology in powder metallurgy with its innumerable innovations from the very beginning. The perhaps most important in-house development in recent years is the patented "Controlled Punch Adapter Technology" (CPA). It comprises seven precisely balanced steps that guarantee optimum product quality – and hence save finishing, time and costs.

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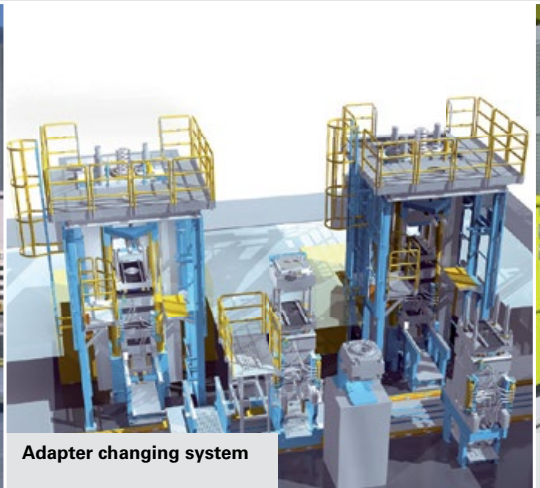
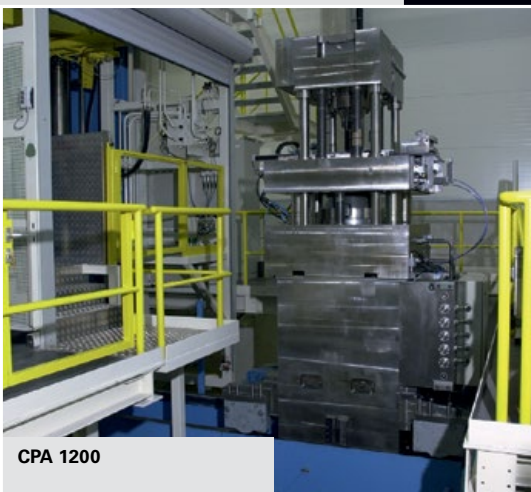


Adapter changing system



CPA 1200

Developments in European powder compaction technology present new opportunities for PM

Continuing developments in powder compaction technology are providing ever increasing opportunities for the production of complex PM components, with advances in press systems and tooling benefitting both the hardmetal and structural parts industries. In this exclusive report for *Powder Metallurgy Review*, Professor Dr-Ing Paul Beiss, RWTH Aachen University, Germany, reviews the state of the market and identifies the advances in die compaction technology for the Powder Metallurgy industry.

When investments are made in powder compaction technology, hydraulic and electric systems are increasingly gaining popularity over mechanical powder presses. Mechanical presses are now more or less restricted to compaction forces below 1000 kN and used mainly for very fast compaction of rather thin one or two cross-sectional parts.

Higher tonnages are served almost exclusively by hydraulic CNC presses, which have penetrated the market down to below 200 kN because of their better height precision and advantages in multi-level or other geometrically complex pressing operations.

Below 1000 kN the servo-electrical presses, launched around three years ago in Europe, have found wide acceptance for hardmetal indexable inserts and now also for more complex components which require several independent punch movements.

Many press manufacturers and suppliers of adaptors offer solutions for radially actuated tool elements, such as side compaction, cross hole compaction or retractable die walls to demould undercut compacts.

Hydraulic powder presses

In the most common design of hydraulic presses the die platen is withdrawn over the lower punch package to demould the compact. For the withdrawal the die platen is connected to the lower press ram via tightly guided tie rods, which end in a slide and T-piece coupling as shown in Fig. 1. The core rod is actuated by a hydraulic cylinder located in the lower ram. The cylinders for the upper punches are attached to the upper ram in a separate adaptor head that is guided by pillars in the die platen.

In this design the die platen is freely moveable versus the package of lower punch platens, of which the base platen is fixed to the press frame, and the adaptor head is freely moveable versus the die platen. Once the active tooling is assembled the die platen and the adaptor head must be prevented from unintended movements by spacers to avoid tool collisions. Only when the base platen, the lower T-piece with the core rod connection and the adaptor head

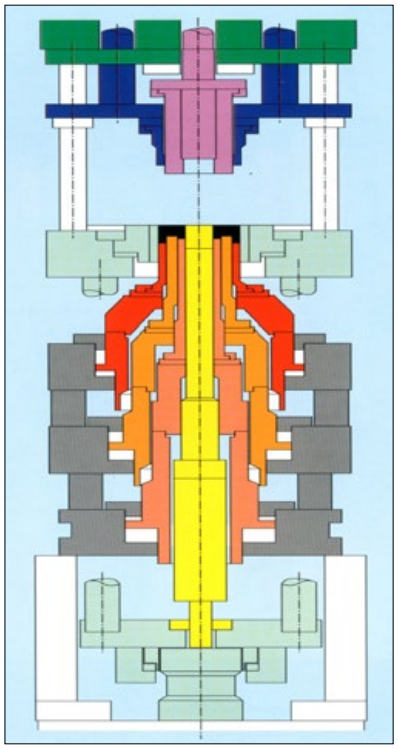


Fig. 1 Traditional hydraulic adaptor with die platen actuation by the lower press ram (Courtesy SMS Meer)

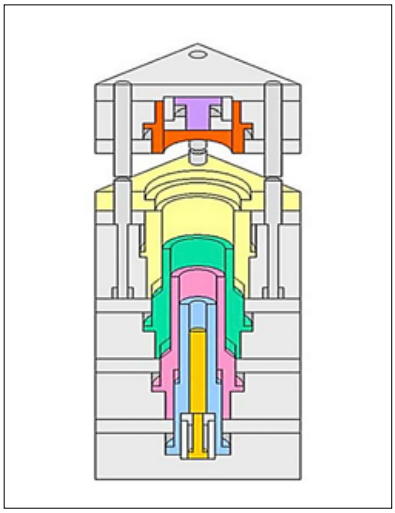


Fig. 2 Adaptor with die platen drive via additional ring piston on top of platens for lower punches [1]

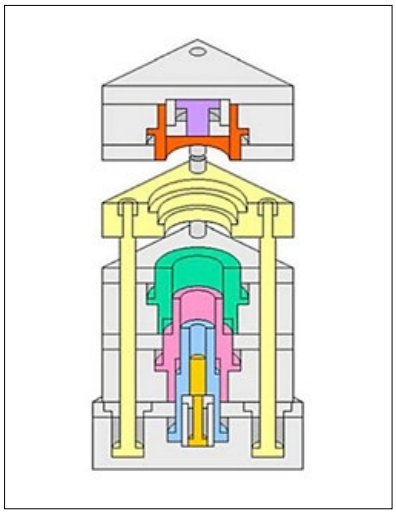


Fig. 3 Adaptor with die platen drive via two opposing lateral pistons in the base platen [1]

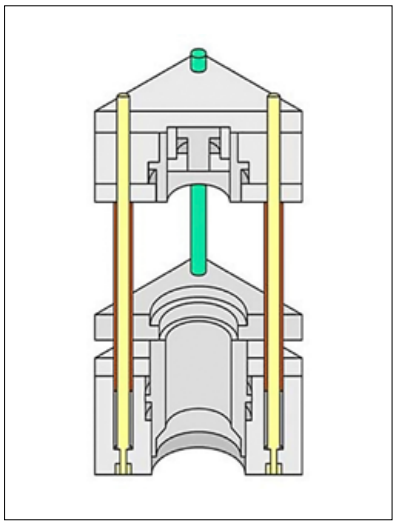


Fig. 4 Adaptor head support by single action ring pistons around auxiliary guide rods [1]

have been clamped to the press, can the spacers be removed.

In older designs all hydraulic couplings must be plugged to their valve blocks to actuate the intermediate lower platens and the additional upper punch cylinders. Even though the adaptor changing times have been significantly reduced by rail systems and hydraulic pull-out and push-in cylinders, recently an attempt has been made to further improve adaptor changes [1].

In the new design the cylinders for the core rod and die are integrated into the lower part of the adaptor (Figs. 2 and 3). The die platen is actuated by an additional hydraulic piston system which can be a ring piston stacked on top of the platens of the lower punch package (Fig. 2) or which may be two lateral pistons in the base platen (Fig. 3).

In the latter case the base platen and the press frame must be wider than in traditional presses, but the total length of the assembly is greatly reduced. The core rod piston is placed centrally in the base platen. Spacers for the adaptor head are avoided with supporting single action ring cylinders, coloured red in Fig. 4, around auxiliary guide rods. The main guiding pillars, coloured green in the background of Fig. 4, align both the die platen and the adaptor head with high rigidity.

"Hydraulic presses are typically equipped with 12 to 18 independent CNC axes to actuate up to six lower and five upper punches"

With this design there is free access to the bottom of the base platen and it is aligned by centering pins and clamped by a central cylinder in the press table. All hydraulic manifolds are automatically docked to connecting panels for the adaptor head and the lower part of the adaptor.

Instead of placing so many hydraulic movements in the adaptor platens there are also designs preferring a dry adaptor platen, without any

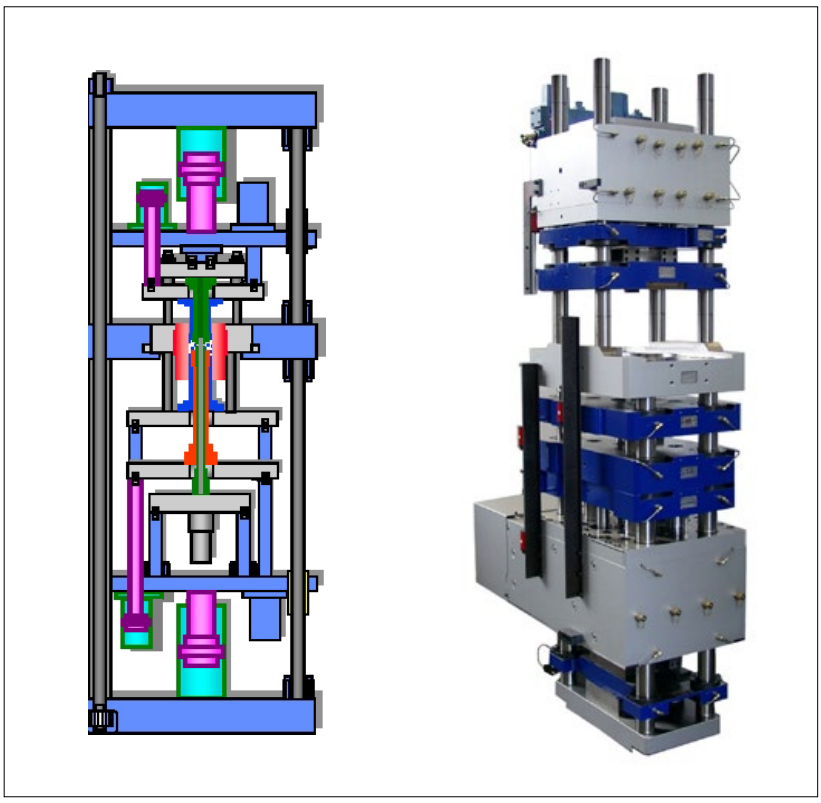


Fig. 5 Cylinder blocks in top and base platen for all adaptor movements except upper crosshead and die withdrawal (Courtesy Komage Gellner)

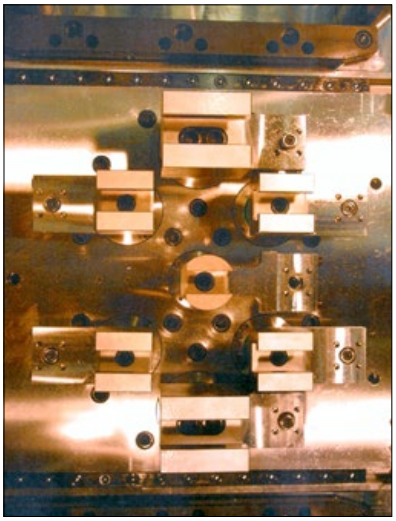


Fig. 6 T-slide arrangement in the press table of a powder press with hydraulic-free adaptor (Courtesy Lauffer Pressen)

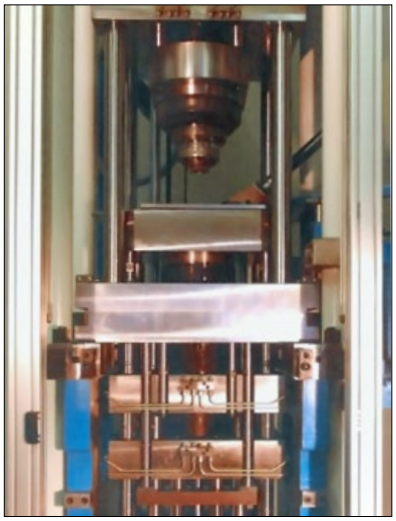


Fig. 7 Forrest of guide rods in a hydraulic-free adaptor (Courtesy Lauffer Pressen)

hydraulics. All pistons are positioned in large hydraulic cylinder blocks, which are the top and base platen of the adaptor, Fig. 5. This principle has been in use for upper punches in hydraulic presses for decades, however only recently it has become available for lower punches.

In a further step towards dry adaptors all hydraulic systems are made part of the press. The platens on which the punches are assembled are connected to their related pistons by symmetrically opposing T-slides in the press table (Fig. 6) and guide rods (Fig. 7). This way any oil leaks and spillages are prevented.

Hydraulic presses are typically equipped with 12 to 18 independent CNC axes to actuate up to six lower and five upper punches, but three or four lower and three upper levels are more the standard. The trend towards more net-shape complexity might require seven lower punches in the future [2].

Electrical Presses

Electrical CNC presses driven by servo-motors of different design were developed over 20 years ago in Japan [3-5] but did not find acceptance in Europe until about three years ago, when both Osterwalder and Dorst presented, independently from each other, prototypes at the Ceramitec 2009 exhibition in Munich (Fig. 8).

The Osterwalder press on the left hand side of Fig. 8 was clearly aimed at the hardmetal industry, with 160 kN capacity and extreme stiffness and height precision. To this end the press was designed without an adaptor, the tools are changed in the press with quick-clamping systems.

The Dorst press shown on the right in

Fig. 8 European prototypes of electrical presses (Courtesy Osterwalder and Dorst Technologies)

Fig. 9 Electrical CNC presses with 150, 300, 500 and 700 kN compaction capacity (Courtesy Dorst Technologies)

Fig. 10 Water distributing ring with four cross holes (Courtesy Institute for Material Research, Slovak Academy of Sciences)

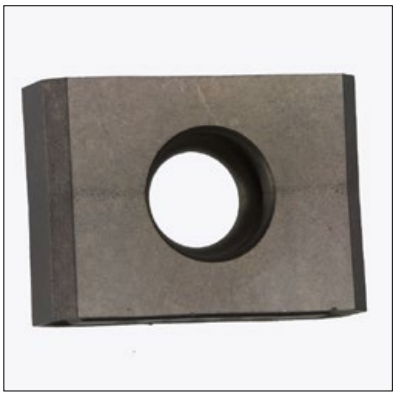


Fig. 11 Cross hole in a grooving insert located precisely in the shear stress-free neutral zone (Courtesy Fette)

Fig. 8 with 120 kN capacity, from the very beginning emphasised more compaction flexibility with changeable adaptors of existing design, but not excluding quick-clamping systems if required.

This general design guideline has been maintained by both companies. Osterwalder now offers two lower and two upper punch drives, with 320 kN maximum capacity, with the focus still the hardmetal industry which has a need of multi-level compaction in some applications. Dorst extended the compaction capacity to 1600 kN and provides up to three upper and lower punch actuating drives with a wholly new adaptor design. The potential customer for this type of press is more a structural part manufacturer, but the design does not eliminate the hardmetal industry.

Fig. 9 shows a range of electrical presses from 150 to 700 kN compaction capacity during a Dorst customer show in 2011. The 700 kN press on the right hand side in Fig. 9 was operating with an H-cross-sectional component comprising a central core rod and three lower and three upper punches.

Komage Gellner has just recently presented the first mechanical-electric hybrid presses, repeating its surprise of 1990 when they launched the first mechanical-hydraulic hybrid press in London. The new design is available with 200 or 300 kN capacity. The upper punch is actuated by a double eccentric and the die platen is driven by a servo-electric torque motor. Presently the equipment is still restricted to one and two cross-sectional geometries.

An overview of the various advantages and compaction possibilities with servo-electrical presses was given in last year's Euro PM2012 in Basel, Switzerland [6]. The advantages can be summarised in short:

- At equal capacity the electrical press requires far less floor space than its mechanical or hydraulic counterpart
- There are no hydraulic leakages
- The presses are, with a noise emission of about 65 dB (A), almost silent
- The energy consumption is much lower than that of a comparable hydraulic press and still lower than that of a mechanical press
- The height precision matches or surpasses that of CNC hydraulics because the position measuring system can be integrated in the spindle.

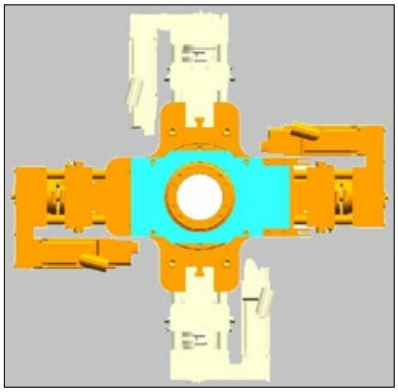


Fig. 12 Newly designed cross hole compaction unit (Courtesy Dorst Technologies)

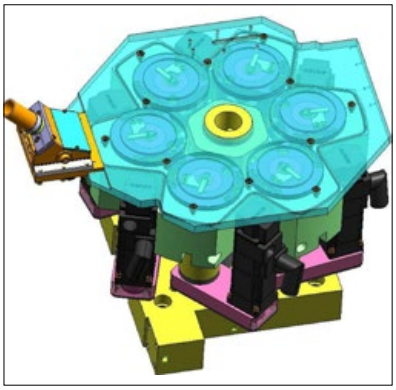


Fig. 13 New side compaction die platen by Dorst Technologies with electric punch drives

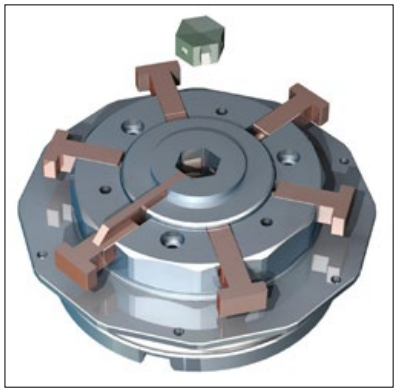


Fig. 14 Principle of Osterwalder's servo-hydraulic side compaction solution, drive units removed

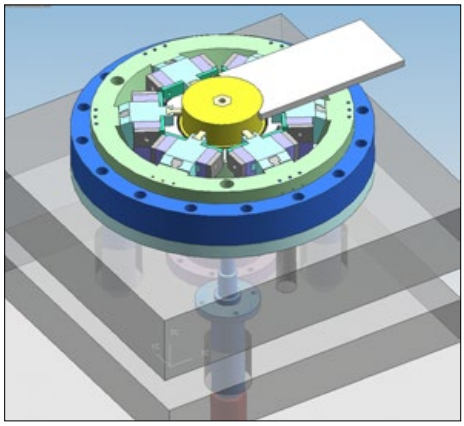


Fig. 15 Mechanical side compaction by Komage Gellner

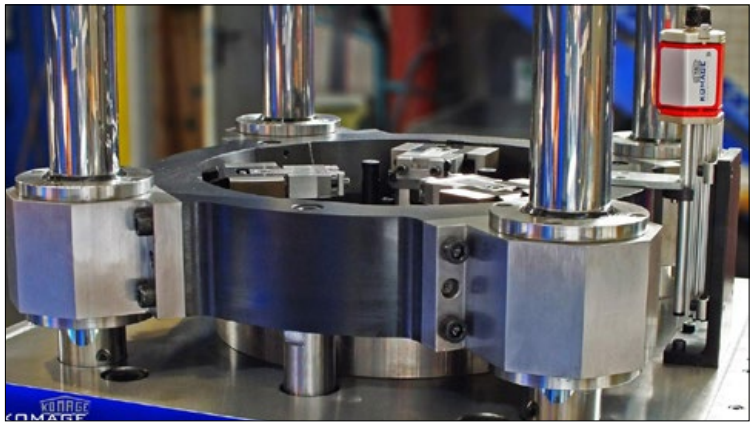


Fig. 16 Three radial punches, die removed, in the mechanical system from Komage Gellner

All these features help make electrical presses a more environmentally favourable investment.

Compaction with radially movable tool elements

Compaction with radially movable tool elements can be separated into cross hole compaction, side compaction and radially split die compaction with removable die walls to demould undercut parts.

The first successful production tools for cross hole compaction were run with a purely mechanical cross pin drive to manufacture water distributing rings for room heaters, a design which is still in use, Fig. 10.

The hardmetal industry in particular challenged the press manufacturers with the request for radial tool movements to compact and demould undercut components. The new developments with hydraulically actuated cross pins became visible to the public with the mass production of indexable inserts for slotting and grooving, which contain contoured cross holes. This type of cross hole can only be formed during compaction with two opposing core pins that advance radially through the die wall and meet with their front faces right in the middle of the cross hole before the die cavity is filled with powder. To avoid damage of the pins the amount of powder below and above the pins must be equal and the cross hole must be located in the shear stress-free neutral zone of the component (Fig. 11).

A new design for a cross hole compaction unit developed by Dorst is shown in Fig. 12 [6]. It consists of a die holder to which, usually, two opposed cross pin drives are laterally attached, with the option of up to four units. The cross pin drives are electrically actuated with programmable travel. The final positions are determined by adjustable stops. This solution is intended to serve the hardmetal industry.

Contrary to cross hole compaction, where the radial elements are in their pressing position before the die cavity is filled with powder, in side compaction the radial pins or punches advance to their pressing position during the axial densification. The side compaction punches contribute at least locally to the final density.

This technology was originally developed by Dorst to form chip breakers into the rake faces of small hardmetal milling cutters. Now the initial design has been modified as shown in Fig. 13. It consists of a special die platen which contains up to six independent closed loop controlled punches which can be freely adjusted in their radial directions. The punches are actuated by an electrical motor, a gear unit and a rotary encoder. The compaction force reaches 30 kN per punch, the position reproducibility is stated as ± 10 µm [6]. In some applications powder presses equipped with side compaction units can geometrically compete with metal injection moulding.

Side compaction with up to six independent servo-hydraulically actuated punches has been developed by

Fig. 17 Mono-column adaptor with part ejection and two removable die walls (Courtesy JAN Entwicklung)

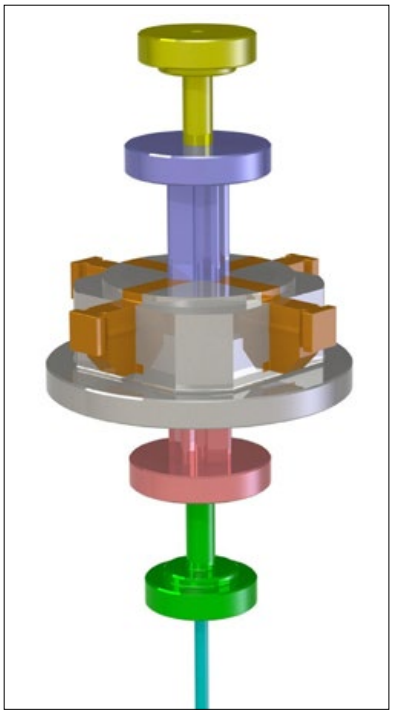


Fig. 19 Tooling principle for the insert in Fig. 18 with radially removable die segments for ejection (Courtesy Osterwalder)

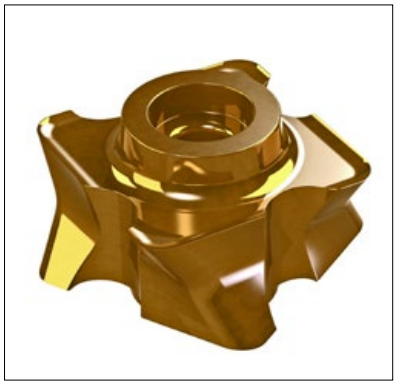


Fig. 18 Indexable insert with undercut corners for high clearance angel (Courtesy Osterwalder)

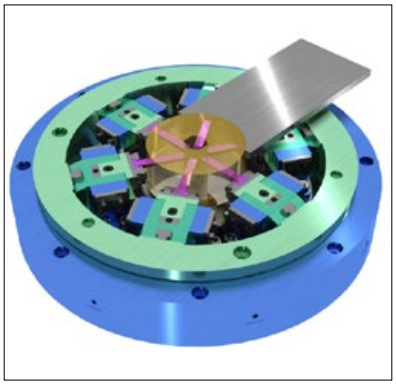


Fig. 20 Side compaction module from Komage Gellner equipped with retractable die wall segments

Osterwalder. Equipped with radial core pins this unit has been demonstrated to also be suitable for cross hole compaction Fig. 14 [7].

Komage Gellner offers a mechanically driven side compaction system as shown in Fig. 15, also with up to six horizontal punches. The radial movement is actuated by ramps in a conical ring (green in Fig. 15), which is servo-hydraulically lifted during the compaction stroke of the press and lowered for punch retraction. A more detailed view is given in Fig. 16 with three radial units and die removed. The principal of actuation is similar to Osterwalder's solution, but the design is different.

All these systems, servo-electrical from Dorst, servo-hydraulic from Osterwalder and mechanical from Komage Gellner, are in use under production conditions in hardmetal applications. In the structural parts industry side compaction is used with lateral forces up to 500 kN for complex undercut geometries, but these configurations cannot be published.

Sometimes geometries, especially hardmetal insert designs, comprise such complex undercuts that they can only be demoulded by radially removing the die walls. In the hardmetal industry this way of demoulding is known as split die technology. In structural part compaction a split die is considered an axially separated die with an upper and a lower die platen.

An early solution with two radially removable die walls is shown in Fig. 17 by JAN Entwicklung, a company which develops among others special purpose servo-hydraulic CNC adaptors for hardmetal compaction. JAN Entwicklung invented the mono-column adaptor visible in Fig. 17, which was later adopted by Fette [7]. The system in Fig. 17 works with ejection demoulding and contains seven CNC axes. A comparable system derived from the principle in Fig. 17 was presented by Fette and is shown in [7].

Most side compaction modules can be used for partial die wall removal if the radial punches are equipped with sufficient force to withstand the radial compaction forces of the powder during pressing. An example of a unusual indexable insert and its compaction tooling is given in Fig. 18 and 19. All four corner segments of the die wall must be retracted to eject the part or to withdraw the die. The side compaction unit from Komage Gellner can also be applied that way in comparable applications (Fig. 20).

Conclusions

The die compaction of powders has now reached a very high level of sophistication, with geometrical complexity, height reproducibility and productivity as never before seen.

Mechanical presses are losing ground in hardmetal and structural part production, with the exception of geometrically simple parts with large production volumes.

With the larger hydraulic presses for complex components, multilevel compaction with three to four lower and three upper punches has become the standard for adaptors. More controlled punch movements are possible if the application justifies the extra expenses. Layered composites can by pressed from different powders, not just for hardmetal drill tips or valve seat inserts, but also for complex structural parts including powder transfers.

The newer electrical presses, with

their many environmental advantages and high productivity, have been quite successful during the last three years, especially in the hardmetal industry. The forming capabilities are, however, steadily extending into the domain of structural parts.

Cross hole compaction, side compaction and radially retractable die walls widen the range of shaping capabilities to three-dimensional compaction, which can sometimes offer die compacted alternatives to Metal Injection Moulded (MIM) parts.

With their many and rapid innovations, the cooperation between press and tool designers is presently the main driver to explore the market for new Powder Metallurgy applications.

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Excellence in powder metallurgy

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Germany's Powder Metallurgy community meets at the 2012 Hagen Symposium

The Hagen Symposium, organised by the Fachverband Pulvermetallurgie, is the annual meeting for many German-speaking powder metallurgists. The symposium took place from November 29-30 2012 in Hagen, Germany, and Dr Georg Schlieper attended the symposium on behalf of *Powder Metallurgy Review*. His report covers a number of key presentations from the event as well as the awarding of the 2012 Skaupy Prize to Dr Lorenz Sigl.

The 2012 Hagen Symposium provided a mixed programme of technical papers covering all Power Metallurgy topics. Organised by the Fachverband Pulvermetallurgie, the German-language event attracted 224 participants from 13 countries.

The first official act at the Hagen Symposium, following the welcoming address by the President, is always the announcement of the Skaupy Prize recipient. This is the highest honour that the Fachverband Pulvermetallurgie confers to distinguished powder metallurgists, and the 2012 recipient was Dr Lorenz Sigl, Head of Innovation Services at Plansee SE in Austria.

In his introductory speech, Prof Bernd Kieback drew a parallel between Dr Sigl's many positions during his academic education and professional career and the brother Grimm's "story of the youth who went forth to learn what fear was". The word "fear" he replaced by "research" alas, the German alliteration between "fürchten" (fear) and "forschen" (research) is lost in the translation!

Dr Sigl grew up in the Austrian province of Tirol and studied mechanical engineering at Leoben. His professional career led him to the Max-Planck Institute Stuttgart, Germany, University of California Santa Barbara, USA, Elektroschmelzwerk Kempten, Germany, and finally Metallwerk Plansee, Austria.

The use of PM in green energy generation

In keeping with the motto of this year's symposium "Powder Metallurgy – at the cutting edge from raw material to the application," Dr Sigl's Skaupy presentation had the title "Powder technology - a source of innovation in energy engineering". In his very broad approach he included both powder metal and ceramic materials. In this condensed report we focus our interest on the powder metal applications.

Powder technology - a source of innovation in energy engineering

The challenges imposed on mankind by global warming call for far reaching changes in the technologies used for power generation. The production of fossil fuels will decline and the emission of greenhouse gases must be reduced.

Fig. 1 The venue for the 2012 Hagen Symposium

Fig. 2 Presentation of the Skaupy Award Certificate to Dr Lorenz Sigl by Fachverband officials. From left: Prof Herbert Danninger, Dr Lorenz Sigl, Prof Bernd Kieback and Hans Kolaska (Courtesy Fachverband Pulvermetallurgie)

Interesting new Powder Metallurgy applications were identified in photovoltaic solar cells, which transform sunlight directly into electric power without any negative side effects, in fuel cells, and in membranes for the separation of hydrogen and carbon dioxide.

These applications have a great potential for growth in the future.

Sputtering targets for solar cells

Instead of crystalline silicon wafers, more and more solar cells are being equipped with a cost efficient thin coating, which is applied on a simple glass or polymer substrate. The most advanced solar cells are made with so-called CIGS coatings that can be as thin as just 1-2 microns. The cost of these modules is less than conventional silicon modules.

The cross-section of such a thin CIGS cell is shown in Fig. 3. At first a molybdenum coating of 0.5 micron thickness is applied. It is compatible with the semiconducting layer on top, reflects the light and has a similar thermal expansion as the glass substrate.

The complex CIGS layer and the Al doped ZnO layer form the active solar cell. They are separated by a chemically deposited CdS layer. The photon energy of the sunlight that hits the cell separates electrons in the CIGS and ZnO semiconductor layers and the resulting voltage can be tapped.

To apply these layers on the substrate, sputtering targets are required. This is where powder metallurgy comes into play. Sputtering targets made by PM have an isotropic structure and the uniformity of the coating is much better than with cast targets. Sputtering targets can be in the form of plates or tubes. The materials are often doped with small amounts of additional elements. This improves the efficiency of the coatings.

The Mo layer, doped with Na, is deposited first, then follows the absorber layer, which is deposited with a Cu/Ga and a In sputtering target. A subsequent reaction in a selenium or sulphur atmosphere leads to the formation of the required CIGS compound.

Metal supported membranes

Dr Sigl identified various applications of membranes with metal powder supporting structures and later in the symposium Hans Peter Buchkremer of Forschungszentrum Jülich further elaborated on this subject. Although serving very different applications, the basic design of these membranes is similar.

The purpose is to separate gas molecules or ions by selective diffusion. The driving force is either pressure or a concentration gradient. This requires a very thin active layer of functional materials, usually semiconductors, which must be supported for mechanical stability and yet be

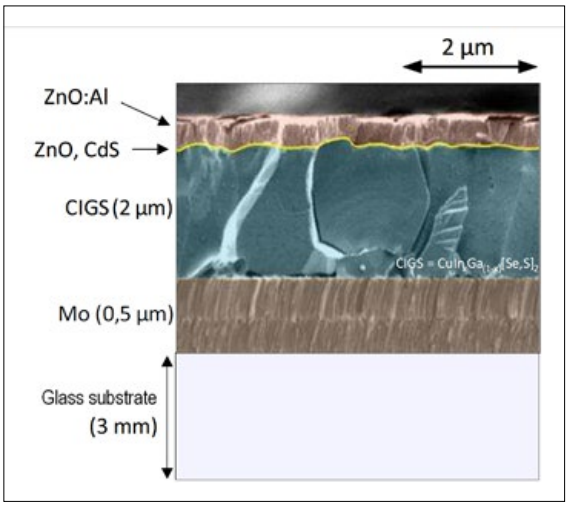

Fig. 3 Coating of a CIGS solar cell (Courtesy Plansee SE)

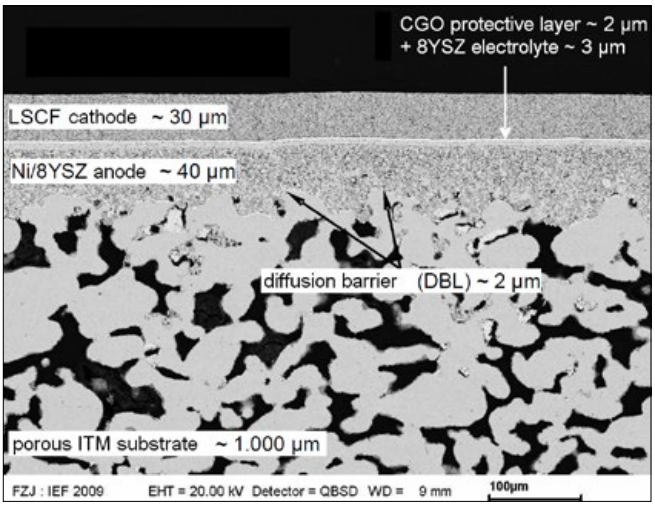

Fig. 4 Cross-section of a metal supported cell (MSC) (Courtesy Forschungszentrum Jülich)

accessible for the gas from both sides. The support can be either a porous ceramic or sintered metal.

Plansee SE is actively developing solid oxide fuel cells (SOFC) for the decentralised, highly efficient generation of electrical power with low emissions. Powder Metallurgy technology is used for the cost efficient manufacture of cell elements and support structures. Fig. 4 shows the cross-section of a metal supported cell (MSC).

The substrate is a highly porous metallic structure made of a Fe26Cr alloy doped with Mo, Ti, yttria (ITM). On top of this there is a deposited layer of Ni/YSZ (yttria stabilised zirconia), which serves as the anode and a complex LSCF cermet layer as the cathode. These two layers are separated by a thin electrolyte layer.Similar membranes can be used to separate hydrogen in steam reforming of hydrocarbons and carbon dioxide from exhaust gases.

The same principle was applied for the interconnectors shown in Fig. 5. These elements are used to support the cell and collect the power. A special chromium base alloy was developed by Plansee with the specific set of properties required for this application. The requirements that the supporting structure has to meet can be explained by taking this example. The advantages of powder metal substrates are the following:

- Mechanical stability, resistance to vibration, ductility even with high porosity
- Thermal shock resistance and stability under cyclic thermal loading
- Applicability of traditional joining techniques such as welding and brazing
- Cost effective raw materials and reduced substrate thickness
- Electrical conductivity and stability in redox cycles.

The main challenge for the development of these elements is the adjustment of the thermal expansion behaviour with the functional layer in order to avoid distortion and cracks.

In conclusion, Powder Metallurgy offers attractive solutions for highly efficient and environmentally friendly future power generating equipment.

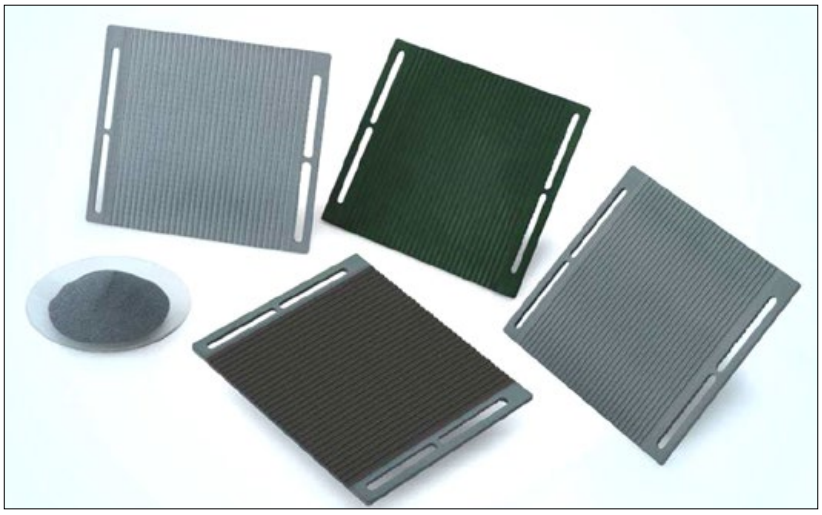

Fig. 5 SOFC interconnectors made from a chromium base alloy (Courtesy Plansee SE)

An insight into REACH regulations for Powder Metallurgy part manufacturers

Since 2006, the European Regulations for Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) has been the reason for serious concerns and tedious discussions regarding the consequences for the PM industry. This extensive and complex legislation has been effective in all EU member states since the 1st July 2007.

A presentation by Bettina Neumann of GKN Sinter Metals Engineering GmbH in Radevormwald, Germany, reviewed REACH and, based on practical experience, picked out the information that is most relevant for PM parts manufacturers.

The burden of proof for recording, evaluating and assessment of material data has been transferred by REACH from the authorities to industry. The new policy is "no data, no market". As a consequence, all participants in the supply chain are responsible for securing human health and the environment with respect to the materials they produce or use.

Companies producing or using hazardous substances are obligated to view with special diligence which materials should remain in their portfolio in the long term. The process of finding practical solutions for implementing REACH that are accepted in the market requires communication with competent partners in the supply chain.

Your role in the supply chain is important

The responsibilities that are imposed by REACH depend largely on the role of the company in the supply chain and the types of products it produces, uses, distributes or imports. Many work areas and procedures in a company are affected, such as Quality Management, IT, Health Safety & Environment, products, materials, liability, documentation and communication.

"The responsibilities that are imposed by REACH depend largely on the role of the company in the supply chain and the types of products it produces"

The role of manufacturers of PM structural parts under REACH is usually that of a Downstream User (DU) as long as they do not produce powder mixtures themselves and distribute them. For powder producers and importers there are other regulations.

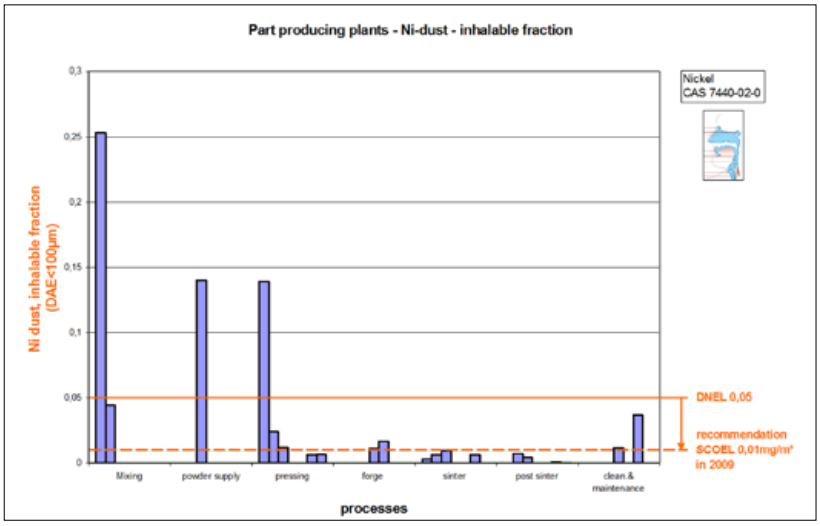

Fig. 6 Inhalable nickel dust levels (Courtesy GKN Sinter Metals)

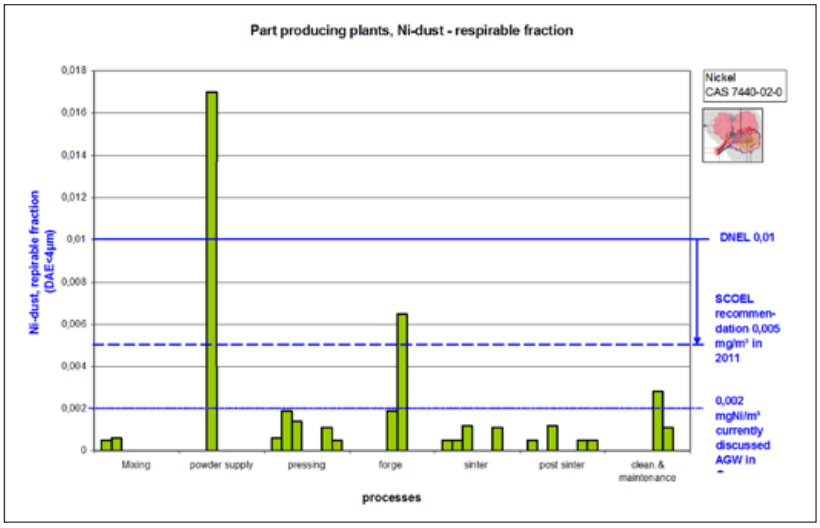

Fig. 7 Respirable nickel dust levels (Courtesy GKN Sinter Metals)

PM parts manufacturers should take care that all raw, operating and auxiliary materials come from EU suppliers or that the invoices are issued within the EU, otherwise they might incur the role of an importer with the associated REACH duties. Imports should always be made through an EU-based office of the manufacturer or an authorised reseller within the EU.

PM parts manufacturers are producers of products. A product is defined as an object which is given a special shape, surface or design that determines its function to a greater degree than the chemical composition. Products are not subject to registration under REACH. In their role as a DU, PM parts manufacturers have the duty to inform their customers about the use of Substances of Very High Concern (SVHC) in their products.

If the content of substances classified as SVHC in the product is greater than 0.1% by weight, the user must be informed immediately. The minimum requirement is the name of the substance and information about the safe handling of the product. This includes surface treatments such as zinc coatings containing CrVI compounds.

Handling nickel powder in the PM industry

Metallic nickel is classified as potentially carcinogenic, skin irritating and hazardous to water. Nickel particles with an aerodynamic diameter (DAE) of less than 100 microns (particle diameter less than 33.5 microns) are considered inhalable and if the DAE is less than 4 microns (particle diameter less than 1.34 microns) they are considered respirable.

Since the average particle size of the most widely used carbonyl nickel is less than 10 microns, nickel dust is inhalable and a fraction of about 1.5% of the particles is respirable, i.e. it can even penetrate into the most delicate and most sensitive parts of the human lung, the aveolies.

EU member states are currently discussing new exposure limits for nickel dust. In order to contribute values of practical experience, GKN measured the nickel dust levels in various areas of its European production plants.

Fig. 6 shows that for the processing steps of powder mixing and pressing, the inhalable dust values can be clearly higher than the suggested "Derived No Effect Level" DNEL of 0.05 mg/m³. If this value is accepted as the legal limit, the PM industry will have to take additional Risk Management Measures (RMM) to minimise the inhalable dust levels. This includes improved dust control, the use of wet cleaning procedures, employing bonded powders, or eliminating or reducing the amount of carbonyl nickel powders used. The limit of 0.01 mg/m³ suggested in 2009 by the Scientific Committee on Occupational Exposure Limits (SCOEL) appears unrealistically low. It has been withdrawn after new insight from animal testing.

These animal tests were carried out with rats, and they showed that respirable nickel particles were not carcinogenic, but toxic on rats. Based on these tests SCOEL proposed an "Occupational Exposure Level" (OEL) for respirable nickel of a maximum 0.005 mg/m³ in 2011. Fig. 7 shows that in many areas the PM industry is already below this extremely low level, but RMM is required particularly in powder supply and cleaning/maintenance.

Hoeganaes develops the master alloy concept to reduce nickel exposure

The global awareness of the risks associated with exposure to fine metallic particles, nickel powders in particular, has increased the need to avoid the use of unbonded additives such as carbonyl nickel powder.

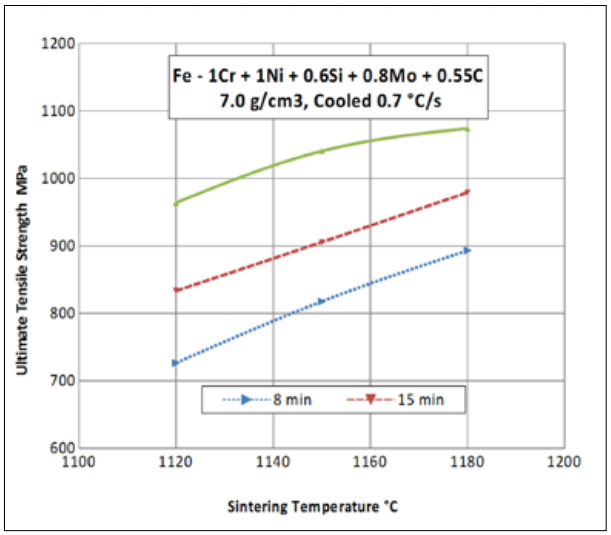

Fig. 8 Strength of Ancorsteel 4300 (Courtesy Hoeganaes Corp.)

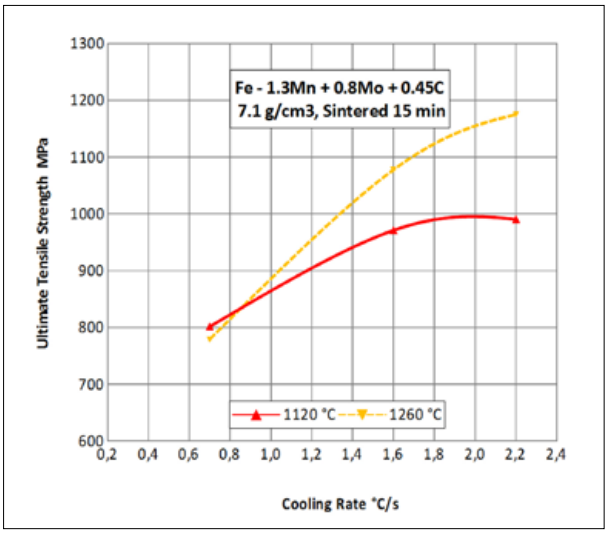

Fig. 10 Strength of Ancorbond FLM 4400 (Courtesy Hoeganaes Corp.)

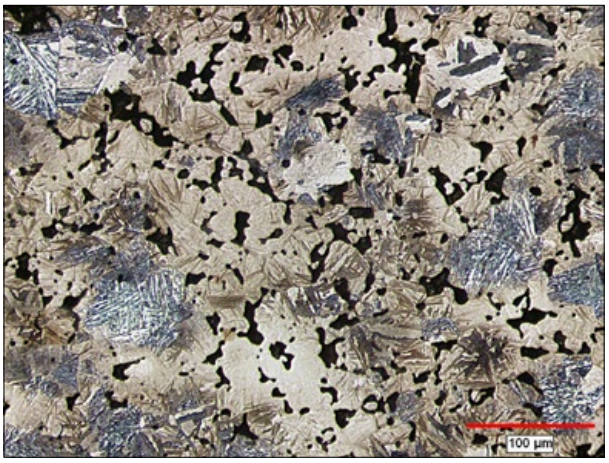

Fig. 9 Microstructure of Ancorsteel 4300 sintered at 1180°C/30 min and cooled at 2.2°C/s (Courtesy Hoeganaes Corp.)

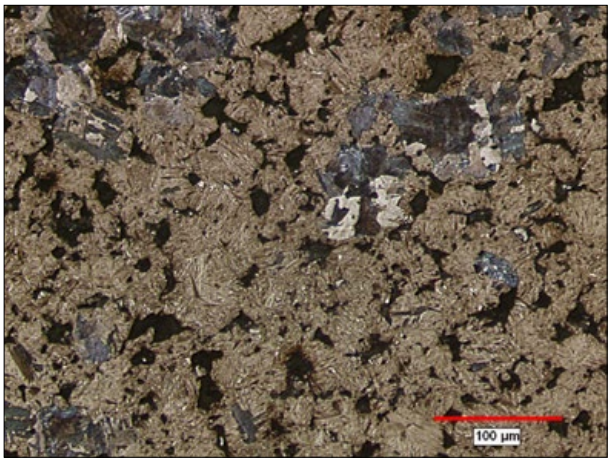

Fig. 11 Microstructure of Ancorbond FLM 4400 cooled at 1.6°C/s (Courtesy Hoeaganaes Corp.)

Michael L Marucci, Director Research & Development at Hoeganaes Corporation, presented the master alloy concept for the replacement of carbonyl nickel in PM steels.

In order to cope with these challenges and for a reduction of alloying costs, Hoeganaes Corporation has developed a number of steel powder grades without the use of carbonyl nickel powder. They are based on Ancorsteel 50HP and Ancorsteel 85HP powders prealloyed with 0.5% and 0.8% Mo, respectively.

Two proprietary master alloys, one containing Ni; Cr and Si, the other one Mn, and natural flake graphite were admixed to these powders. Ancorbond technology was applied to firmly attach the graphite and master alloy powder particles to the steel powder with a binder. The alloy compositions were designed for sinter hardenability, resulting in properties that meet or exceed more highly alloyed diffusion alloys.

Ancorsteel 4300

The powder grade Ancorsteel 4300 contains 0.8% Mo (prealloyed), 1.0% Ni, 1.0% Cr, 0.6% Si (master alloy) and 0.6% graphite (admixed), balance iron. The processing parameters and material properties were compared to a diffusion alloyed grade FD-0405 and a fully prealloyed Fe-Ni-Mo PM steel.

The compressibility of the 4300 grade at 550 MPa is at 7.0 g/cm³, only slightly less than the diffusion alloyed grade (7.03 g/cm³) and clearly better than the fully prealloyed grade (6.91 g/cm³).

Sintering Cr and Si containing PM steels requires particular attention to the sintering atmosphere since these elements form stable oxides that are difficult to reduce. The preferred sintering atmosphere is N_2-H_2 with a minimum of 5-10% hydrogen to ensure good reduction of surface oxides.

The attained ultimate tensile strength of Ancorsteel 4300 is shown in Fig. 8 depending on the sintering temperature and time. The results show clearly that a sintering time of 30 minutes is required and that the sintering temperature should be at least 1150°C, better 1180°C, to fully utilize the alloying elements. With these processing parameters the steel attains an apparent hardness of 27 HRC and the dimensional change from die exhibits a slight shrinkage of -0.11% (1150°C) or -0.18% (1180°C).

The microstructure of this material sintered at 1180°C/30 min with a cooling rate of 0.7°C/s is mostly martensite with remaining areas of bainite. The master alloy has diffused

into the structure to a high degree. This set of sintering conditions gives the highest strength of the test matrix. If the cooling rate is further increased to 2.2°C/s, the apparent hardness after tempering at 205°C can be increased up to 41 HRC.

Ancorbond FLM 4400

While the grade Ancorsteel 4300 still contains a small amount of nickel in the form of a master alloy, Ancorbond FLM 4000 and Ancorbond FLM 4400 are completely nickel-free. The chemical composition is 1.3% Mn, 0.5% (0.8%) Mo, 0.6% graphite, balance iron. Due to the chemical reaction of carbon with oxides and the atmosphere, the final carbon content after sintering was reduced to 0.45%C.

Like chromium, manganese containing PM steels require special attention when sintering due to manganese's higher affinity for oxygen relative to more traditional alloying elements such as nickel or copper. Dry N_2-H_2 atmospheres should be used with dew points < -40 °C with a minimum hydrogen content of 5-10 vol.%. A sintering temperature of 1120°C is sufficient to attain high strength and hardness values, but high temperature sintering at 1260°C leads to less dimensional growth and complete homogenisation of the master alloy.

The Mn alloy steels exhibit a significant growth after sintering. At 1120°C the dimensional change is +0.4% and at 1260°C it is +0.3%. Slight differences may occur depending on the cooling rate.

The most pronounced effect on the mechanical properties is that of the cooling rate, as shown in Fig. 10. All samples were tempered at 205°C/1 h after sintering. The strength depends mainly on the amount of martensite formed during cooling and increases with the sintering temperature and the cooling rate. Correspondingly, the apparent hardness increases from around 20 HRC at 0.7°C/s to 33 HRC at 2.2°C/s.

While atmosphere heat-treatment and quenching is difficult with this alloy system it has been shown that this material system can very well be locally induction hardened because the time at the temperatures where oxidation takes place is very short.

Microstructures of the test samples were also inspected. An example is shown in Fig. 11. The sample cooled at 1.6 °C/s has a microstructure that is mostly martensite with a small area fraction of bainite. This hardened structure explains the high strength and hardness observed. The high temperature sintered samples also have a microstructure that is mostly martensite, but the porosity is smaller and more rounded.

The master alloy concept is attractive for high strength PM parts that use sinter-hardening. It avoids the use of free nickel and offers relatively low alloying costs for a good response to heat treatment.

"The advantages of PM manufacturing, suggested Szabo, will undoubtedly lead to increased applications for powder metal parts as environmental issues become ever more important"

The prealloyed powder concept to replace carbonyl nickel

It has widely been recognised that the use of carbonyl nickel powder must be avoided in order to satisfy the aggravated limit values for nickel dust in working environments.

In this article we report on presentations by Christophe Szabo of Höganäs GmbH and Robert Daniszewski of Pometon SpA, who discussed their concepts for the replacement of carbonyl nickel based on prealloyed powders.

Höganäs Astaloy CrA, Astaloy CrM, Distaloy AQ

Höganäs AB, Sweden, distributes its diffusion alloyed powders under the trade name Distaloy and prealloyed powders under the name Astaloy. In the first part of his presentation, Christophe Szabo outlined the ecological impact of PM technology in comparison with wrought steel technology.

The advantages of PM manufacturing, suggested Szabo, will undoubtedly lead to increased applications for powder metal parts as environmental issues become ever more important.

Höganäs' strategy for high strength nickel-free structural parts is clearly in favour of using prealloyed powders rather than master alloys because they believe that the activity of alloying elements is better utilised. The company has invested a lot of effort to overcome the supposed lack in compressibility of prealloyed powders.

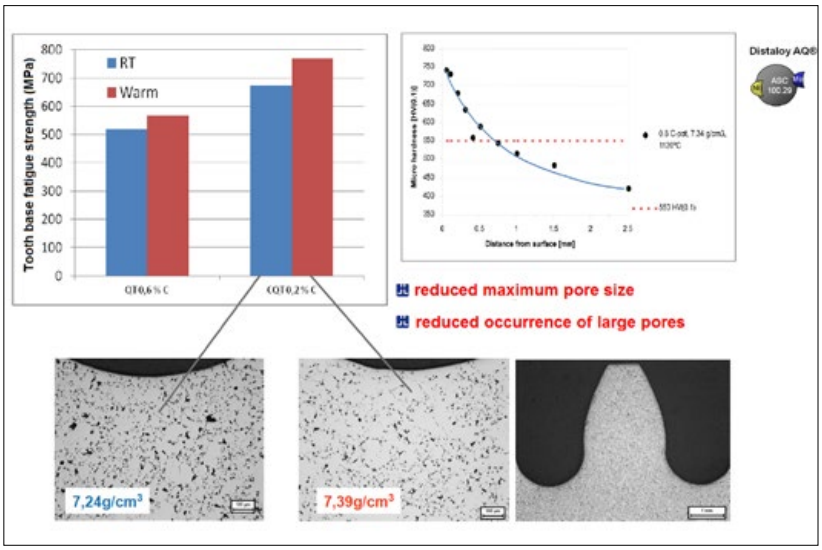

Fig. 12 Tooth base fatigue strength (Courtesy Höganäs)

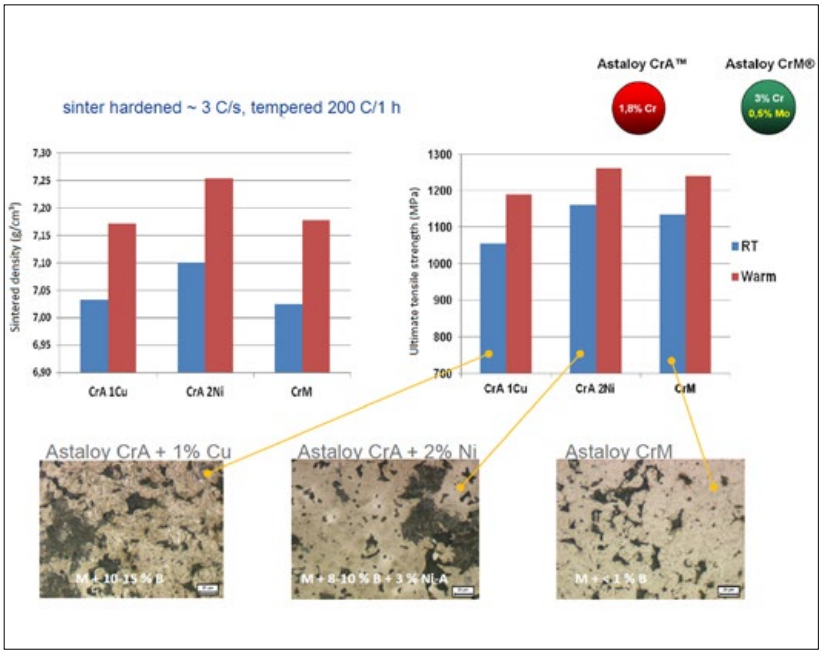

Fig. 13 Properties of chromium containing PM steels (Courtesy Höganäs GmbH)

Besides this, however, Höganäs further pursues the diffusion alloying concept, including the use of carbonyl nickel in its compositions.

The high performance alloys presented by Christophe Szabo are based on the grades Astaloy CrA (1.8% Cr), Astaloy CrM (3% Cr-0.5% Mo) and Distaloy AQ (0.5% Ni, 0.5% Mo).

Distaloy AQ was investigated with a carbon content of 0.2%C for case hardening (CQT) and 0.6%C for quench-and-temper (QT) heat treatment. Green densities at compaction pressures of 700 MPa were reported to be at 7.15 g/cm³ for cold compaction and 7.32 g/cm³ with warm compaction. After sintering at 1120°C/20 min under N_2/H_2 90/10 atmosphere the densities were 7.24 g/cm³ (cold compaction) and 7.39 g/cm³ (warm compaction) for Distaloy AQ + 0.2%C and 7.15 g/cm³ and 7.3 g/cm³ for Distaly AQ + 0.6%C. Heat treatment was done at 860°C/20 min, oil quench and tempering at 200°C.

Particular interest was given to the properties required for gear applications (Fig. 12). The highest tooth base fatigue strength was achieved by warm compaction and case hardening. It was reported that warm compaction does not only lead to the highest densities, but also the maximum pore size is reduced and the occurrence of large pores is reduced as well.

The prealloyed grades were processed into three alloys, namely Astaloy CrA + 1% Cu + 0.65% C, Astaloy CrA + 2% Ni + 0.6% C, Astaloy CrM + 0.5% C. As shown in Fig. 13, these alloys can achieve sintered densities well above 7.0 g/cm³ and tensile strength values above 1000 MPa after sinter hardening with a cooling rate of roughly 3°C/s. Remarkably high fatigue strength values were also reported.

ECOSINT prealloyed powder grades developed by Pometon

The challenges imposed on the PM industry by economic, metallurgical and legal aspects stimulated Italian powder producer Pometon to develop a new family of Cr-Mo-Ni alloyed sinter hardening steel powders under the trade name ECOSINT.

By fully exploiting the synergy effects between the individual alloying elements it was possible to reach a critical cooling rate of as low as 0.45°C/s with a low total alloying content. These powders allow parts manufacturers to realise sinter hardening effects without the need for a separate accelerated cooling step. The martensitic or bainitic microstructure of these high performance PM steels guarantee excellent properties and dimension reproducibility.

The alloys Fe-1.4% Cr-0.8% Mo-0.4% Ni-0.3% C and Fe-1.4% Cr-0.8% Mo-1.0% Ni-1.0% Cu-0.8% C were investigated. The powders were cold compacted to a density of 7.05 g/cm³, sintered in an industrial furnace at 1120°C under N_2/H_2 90/10 atmosphere with a normal cooling rate of 0.25°C/s. The low carbon version was subsequently carburised to achieve the required apparent harness of 35 HRC. Compacts made from the high carbon alloy were sintered in a laboratory furnace at 1120°C and 1240°C/30 min and cooled at a rate of 0.95°C/s followed by tempering at 200°C/1 h.

The carburised part attained a carbon content of 1.0% and was through-hardened. The microstructure was fully martensitic and the apparent hardness was 41 HRC.

The high carbon alloy was fully martensitic with traces of retained austenite and achieved a hardness of 34 HRC independent of the sintering temperature. The carbon content after sinter hardening was 0.74% and 0.61% C, respectively.

Pometon claims that the ECOSINT formula is an attractive compromise offering high mechanical properties, easy-to-handle processing conditions and low alloying content. This new family of PM alloys based on the combination of three alloying elements, Cr, Mn and Ni, is characterised by an excellent response to carburising or sinter hardening heat treatment.

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Industry suppliers exhibit at the 2013 Hagen Symposium

The exhibition at the Hagen Symposium once again proved popular, with some 57 companies displaying their products and services in the lobby areas of the venue.

In combination with the moderate exhibition fee charged by the organisers this exhibition is affordable and finds a high quality audience of well educated PM engineers and decision-makers.

Exhibition area on the ground floor

The major part of the exhibition space was occupied by the main raw materials and equipment suppliers of the PM industry. However, there were not just the big players, but also many smaller, specialised companies. In fact, some of the biggest suppliers were not represented with a stand because their headquarters are outside Germany and its neighbouring countries.

When we look at the powder suppliers, there were specialists like Carpenter Powder Products, ECKA Granules, Erasteel, K-mat, and Pometon, as well as bmv-Burkard Metallpulververtrieb GmbH, a re-seller. Equipment for powder characterisation and processing by milling, blending and kneading was exhibited by Eirich, Micromeritics and Netzsch. Suppliers of organic powder additives and binders as well as MIM feedstock were represented by Inmatec and Zschimmer & Schwarz.

Powder presses were exhibited by Dorst, Fette, Komage Gellner, Lauffer, Osterwalder, and SMS Meer. The importance of this industry in central Europe is reflected by the large number of exhibitors. Cold and hot isostatic presses were presented by EPSI and Bodycote HIP. Surprisingly, however, there was no manufacturer of injection moulding machines in the exhibition.

There were several specialists offering services with close relationship to powder pressing such as compaction tooling (Alvier), tool clamping systems (Erowa, ProGrit) and tool adaptors (Sumca). Special PM steels were on display by Deutsche Edelstahlwerke.

Exhibition area on the upper level

Visitors with an interest in sintering furnaces had the opportunity to get an almost complete over-view of the various types on the market. Manufacturers of continuous furnaces (Cremer, Elino, Mahler) were equally present as those of discontinuous furnaces (ALD Vacuum Technologies, FCT Systeme, MUT Advanced Heating, PVA TePla, TAV Tecnologie Alto Vuoto, Thermal Technology, Tisoma). Furnace supplies were offered by Kerafol (ceramic setters) and Linde (gases).

Equipment for post-sintering treatment presented in the exhibition included high performance lubricants for sizing and machining (Bechem), heat treatment furnaces (Rubotherm, Rübig), plasma nitriding (Eltro), coating (Holzapfel), and waterjet cutting (Maximator JET). Other operating supplies are available from Glass GmbH.

Further services for the PM industry were offered by Ahotec and W.S. Werkstoffservice (materials testing), Insitut Dr. Förster (magnetic properties), Medav (acoustic testing), Porotec (porosity measurement). GreCon Greten GmbH provided consulting and equipment for effective fire prevention. The wide range of thermal analysis equipment offered by Linseis is inevitable for many tasks in PM research.

A number of universities and research organisations offered their competence in Powder Metallurgy research and consulting including Fraunhofer Institutes IFAM and IKTS, Leibniz University Hannover IFW, RWTH Aachen IWM, TU Dortmund ISF. The MIM Expertenkreis and the private consulting agency PMCtec were also present.

"This well-furnished exhibition provided interesting and colourful surroundings for the technical sessions of the symposium"

This well-furnished exhibition provided interesting and colourful surroundings for the technical sessions of the symposium. In addition to their exhibition stands, exhibitors had the opportunity to present their products to the audience in two sessions of short five minute presentations.

The exhibition at the Hagen Symposium demonstrated the great variety of supplies and services required by the PM industry. It is always a forum for networking and making new acquaintances rather than a mere trade exhibition. Young Powder Metallurgy engineers in particular are addressed by the annual symposium and the exhibition, where they find first hand information about the state-of-the-art and recent innovations in PM technology.

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PM-13: India's annual PM conference and exhibition attracts an international audience

Organised by the Powder Metallurgy Association of India (PMAI), the PM-13 International Conference & Exhibition on PM for Automotive and Engineering Industries took place at the Hyatt Regency Pune, India, from February 7-9 2013, alongside the 39th Annual Technical Meeting of the PMAI. In this exclusive report for *Powder Metallurgy Review*, Professor Ramamohan Tallapragada provides an overview of the conference and highlights a number of key presentations made during the event.

The city of Pune provided a warm welcome to around 300 delegates attending the PM-13 Conference and Exhibition. The Powder Metallurgy Association of India (PMAI) had chosen to return to Pune, recognised as one of India's main auto hubs, following the successful event held in the city in 2011.

It is clear that the popularity and support for the PMAI's international conference is growing each year. As well as increased delegate numbers, the event was helped by companies such as Höganäs India who organised two pre-conference workshops, one on gears and the other their popular "Power of Powder" seminar. Battelle India also supported the event by inviting PM CEOs to a pre-conference get together, panel discussion and dinner on 6th February at the Conference venue.

PM-13 began with P N S Sivan, President of the PMAI, welcoming all delegates, guests and dignitaries to the conference. The welcome was followed by the official opening of the event with a traditional Lighting the Lamp ceremony (Fig. 1).

In the inaugural address by Dr Ajit Kumar Jindal, Head of Engineering Commercial Vehicles, Tata Motors, the importance of engineering safety into a vehicle was stressed. This, according to Jindal, is best done by the collective participation of all the stakeholders. He also highlighted the importance of technology road maps and invited PM industries to actively participate in technology oriented projects.

During the opening session Hans Söderhjelm, Höganäs AB, Sweden, discussed developments in new powders and highlighted the importance of metal powders in Additive Manufacturing (AM), with special

Fig. 1 PM-13 was opened with a traditional Lighting the Lamp ceremony. Pictured left to right: Greg Lavallée, P Ramakrishanan,T R Rama Mohan, Hans Söderhjelm, Ajit Kumar Jindal, K Murligopala Krishnamoorthy and P N S Sivan

Fig. 2 Presentation of FPMAI awards (left) Dr A K Jindal to Mr. Palwankar, (centre) Dr S N Vaidya accepting on behalf of U Basak and (right) to Prof Dr Henning Zoz

Fig. 3 Dr Ajit Kumar Jindal, Head of Engineering Commercial Vehicles, Tata Motors, opened the exhibition (left to right) Murligopal Krishnamoorthy, Greg Lavallée, Hans Söderhjelm, T R Rama Mohan , P N S Sivan, P Ramakrishnan and N Chandrachud

reference to Digital Metal, a division recently formed by Höganäs.

Greg Lavallée of Rio Tinto Metal Powders, Canada, presented an overview of the Powder Metallurgy market and looked at main drivers of worldwide PM growth. In contrast to forecasts of a world automotive CAGR of ~4% (2013–2019), the Indian Powder Metallurgy market is expected to have a CAGR of ~9% (2013–2019). Further improvements will be seen in low cost export capabilities and increased powder metal content per vehicle, stated Lavallée.

Other positive and negative drivers for PM were identified as material substitution, performance versus relative cost, size of vehicles and the evolution of fuel economy standards. Lavallée added that Rio Tinto Metal Powders has a positive long term outlook for Asia, and India in particular, concluding that the future remains bright for low cost, technologically innovative parts and powder producers.

Award presentations

Three prestigious Fellow of PMAI (FPMAI) awards were presented at PM-13. Dr Prof Henning Zoz received one for his sustained contribution to PMAI and PM in India, Mr Palwankar for his outstanding contribution to helping the small scale PM industry in India and Uddharan Basak for his contributions to PMAI and PM in Nuclear Engineering (Fig. 2).

The PM-13 exhibition

The PM-13 exhibition was opened by Dr Ajit Kumar Jindal, Tata Motors (Fig. 3). A total of 24 manufacturers displayed their powders, components and equipment, in what was by far the largest exhibition yet organised by the PMAI.

Special session focuses on Additive Manufacturing

PM-13's special session on Precision & Additive Manufacturing began with a presentation from Prof K P Karunakaran, Mechanical Engineering Department, IIT Bombay, who traced the beginnings of Additive Manufacturing (AM) back to 1987. This, he stated, was when 3D Systems launched its Stereo-Lithography Apparatus (SLA) and demonstrated a new way of manufacturing through addition (Fig. 4). New processes known as Rapid Prototyping (RP), 3D Printing or, more appropriately, Layered Manufacturing (LM) then came into vogue.

The production of effective tools via this process resulted in a drastic reduction in time-to-market and the capabilities of RP expanded in terms of materials, quality and process capabilities. Initially only polymer components were manufactured, however capability increased to include ceramic and metallic parts.

Several post-build processes have emerged to improve the surface quality, for example liquid polishing, and material integrity such as Hot Isostatic Pressing. RP and AM in conjunction with these post-build processes allow for the rapid development of even very complex products such as those used in aero engines.

Prof Karunakaran identified some of the unique capabilities of RP and AM as allowing:

- Components/tools with conformal cooling channels
- Objects with gradient materials
- Components of non-equilibrium materials
- Assemblies without joints (elimination of welded joints)

- Difficult/impossible shapes by other means
- Customised solutions for aesthetic, ergonomic and bio-medical applications.

3D Printing

It was suggested that the term 3D Printing refers to economical AM processes, with equipment in the range of USD $5,000-25,000, which can be part of any design office just as with 2D printers. This equipment is only suited to the quick physical realisation of a design for visualisation and review.

Rapid Prototyping

Rapid Prototyping (RP) is a more advanced form of this process, which caters to primarily polymer components, but with assured quality and wide variety of materials so that they can be used for more complex applications of form, fit and functional tests.

Rapid Manufacturing

Rapid Manufacturing (RM) is seen as the highest level which includes metals and ceramics and goes beyond prototyping. RM, through its many facets of direct and indirect routes (Vacuum Casting, Epoxy Tooling, Rapid Casting etc.), can be useful in regular production as well. While 3D printing and RP have linearity of cost with quantity, RM has the distinction of cost reduction with quantity.

Deepak Grover and Hans Söderhjelm, Höganäs Digital Metal, described Additive Manufacturing as a process of building components in layers directly from 3D CAD data, without the need for complex and expensive tools and with minimal waste material. Unlike Rapid Prototyping, Additive Manufacturing goes to the next level by being able to mass produce end user products.

Höganäs Digital Metal, stated Grover, offers a revolutionary and innovative manufacturing technique for metallic components. It is a proprietary precision ink-jet technology for Additive Manufacturing and 3D printing of metal components and systems. This offers a unique capacity to rapidly and cost effectively produce highly complex and intricate designs and features for metallic parts (Fig. 7).

Dr Mukesh Agarwal, 3D Product Development (3DPD), Bangalore,

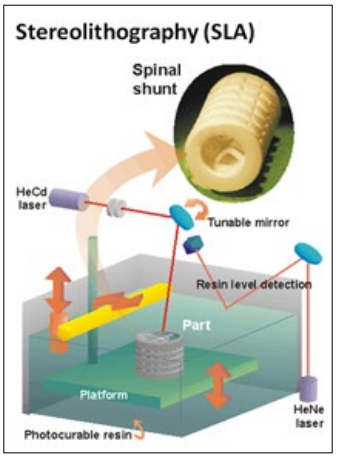

Fig. 4 Layers of UV sensitive liquid polymer are solidified using a laser (Courtesy 3D Systems)

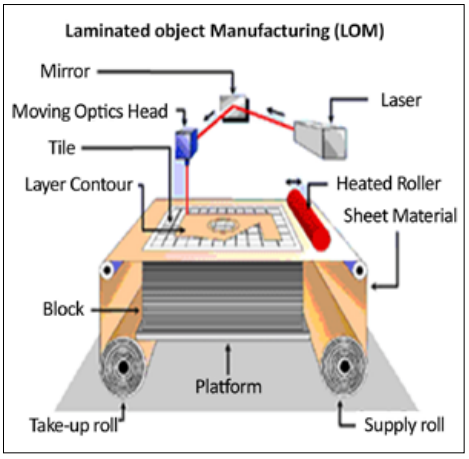

Fig. 5 LOM bonds and cuts sheet material using a computer guided laser (Courtesy Helisys)

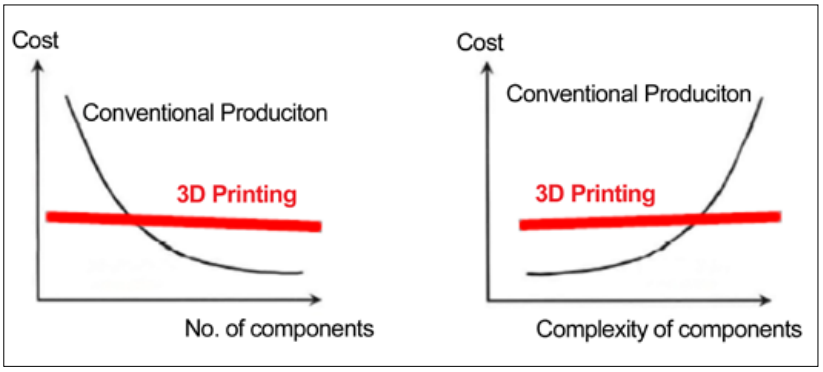

Fig. 6 Cost comparisons for production of components via Additive Manufacturing (Courtesy Höganäs)

stated that today's product development requirements have become more demanding, with the gap between product design cycle and mass manufacturing often required to be bridged by low volume production quantities. The product life cycles became shorter and, in many cases, products are being designed for limited volume.

This demand for low volume production has resulted in conventional Rapid Prototyping processes being adapted and adopted as "Additive Manufacturing" for low volume production. According to Dr Agarwal, given material limitations with traditional Rapid Prototyping processes, these processes are sometimes not even suitable to produce fully functional prototypes.

Powders and feedstock

Dr Rama Mohan R Tallapragada, Consultant, Mumbai, India, discussed the importance of powders and feedstock for successful Additive Manufacturing. During his presentation he referred to his paper presented during PM-02, the 2nd International conference on Powder Metallurgy in Automotive Applications held at New Delhi in 2002. That paper dealt with the then emerging techniques of Rapid Prototyping and their usefulness. A decade later his presentation discussed the rapid changes in the technologies such as production of

Fig. 7 Digital Metal was used to manufacture this Klein Bottle Opener (Courtesy Höganäs)

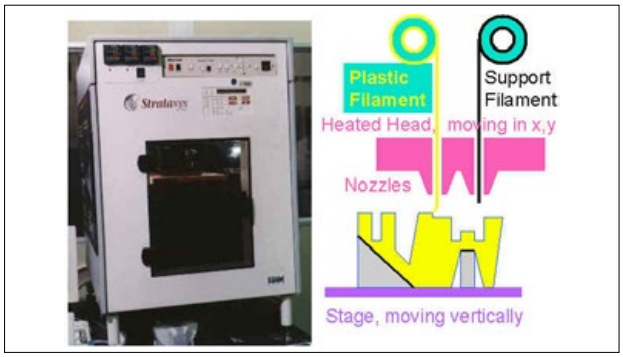

Fig. 8 FDM extrudes thermoplastic materials in filament form to produce parts layer by layer (Courtesy Stratasys)

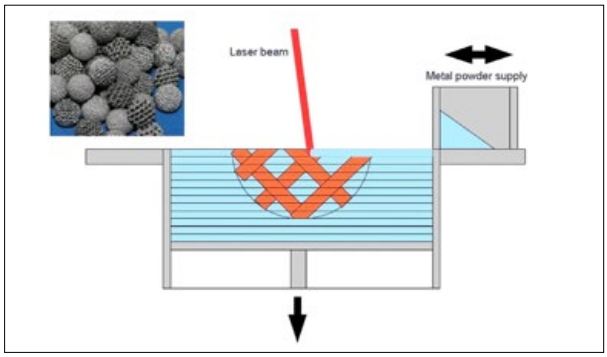

Fig. 9 Production of structured spheres by selective laser sintering (Courtesy FIT)

prototypes, visual design aids, touch, feel, fit and assembly test parts that are used in the product development phase. For the real production of parts at all levels the technology had evolved into Rapid Manufacturing. These generally refer to techniques that produce shaped parts by gradual creation or addition of material, as distinguished from forming and manufacturing through material removal.

The need for the production of complex components with little or no machining via PM techniques has seen Powder Injection Moulding (PIM) become a popular processing technique. The tools and dies required for PIM are themselves complex and in order to process these, Rapid Prototyping or Solid Free-form Fabrication (SFF) have been utilised.

A CAD model of the required free-form is created and converted into a STL format (after the process Stereo Lithography, developed by 3D systems). The latter is sliced into thin cross-sectional layers and the output is fed to the Rapid Prototyping machine which then builds the free-form, one layer at a time. The free-form is then sintered to yield the final product.

Many layered manufacturing techniques are in vogue, with the most popular being: photo-polymerisation (Stereo lithography (SLA) and its derivates), ink-jet printing (IJP), 3D printing, Fused Deposition Modelling (FDM) (Fig. 8), Selective Laser Sintering or Melting (SLS/ SLM and EBM) (Fig. 9) and to a lesser extent Laminated Object Manufacturing (LOM and similar sheet stacking processes) and Laser Cladding (LC) processes. Many of the techniques are, however, limited to Rapid Prototyping as they do not allow common engineering materials to be processed with sufficient mechanical properties.

Rapid Manufacturing techniques are extensively used in processing ceramics and ceramic-polymer composites. The most popular techniques for metal powders are FDM and SLS. The latter often uses metal powders along with polymers. Complex shapes such as gears, turbine blades, etc., can be produced.

Metal powders for laser sintering are generally spherical, fine and gas atomised. Where non-spherical powders are to be used these should be coated with a polymeric binder and mixed to form loose agglomerates and then coated with lubricant/plasticiser to minimise frictional forces and cause easy sliding.

In conventional sintering the particles are not fundamentally changed, unlike in laser sintering where the particles are fully or partially melted. Necessary feedstock properties include being free flowing with a size that must allow a reasonable finish. The binder must melt and "backbone" the powder to deliver required properties. Powder flow is affected by particle shape and size distribution, but the finer the powder the less it flows with, it was suggested, the best combination being <50 μm and rounded.

The technology, however, is in the early stages as far as Powder Metallurgy applications are concerned. Developing a proper powder mix is a considerable challenge to the powder producers as it involves new generation inks, gels, pastes and powder blends. Some of the feedstock can be in the form of metal powder-polymer blends, wires, rods or granules.

"Powder flow is affected by particle shape and size distribution, but the finer the powder the less it flows"

Advances in powder technology and processing

The PM-13 conference included a number of presentations focused on developments in powder technology and processing.

Höganäs AB

Höganäs presented several papers related to the development and use of its machinable Fe-Cu-C mix. The usual machining aid, MnS, is suspected to form agglomerates in presence of moisture and can cause rust in the product. The solution to this region specific problem is found in the form of the company's Fe Cu C mix which required no addition of MnS but still produced parts with good machinability.

The powders are produced by a combination of the right scrap, strict melt control techniques and by optimisation of atomisation and subsequent annealing parameters. The method of storing the ingredients, time of mixing, speed of mixing, atmosphere in the mixer, loading and unloading methods are some of the parameters that were studied and optimised. These parameters were also found to be sensitive to the location where the mixes are produced. The machinability tests showed the benefits of using Fe-Cu-C mix (Fig. 10).

Pometon S.p.A

Ilaria Rampin, Pometon S.p.A., Italy, stated that the volatility of the price of raw materials, as well as the European Union regulations related to Ni and Cu, had forced Pometon to find leaner alternatives to current ferrous alloys for structural applications. Two strategies were pursued, either optimisation of the content of traditional alloying elements or the introduction of Mn through proprietary alloying techniques.

Ni-Cu-Mo diffusion bonded iron powder was used as base powder and mixed with three different levels of Mn (0.65-0.85-1.05%) together with three levels of graphite (0.4-0.6-0.8%) and with 0.8% lubricant. Specimens made from these powders were sintered at 1120°C, 25 minutes under $86N_2$-$12H_2$-$2CH_4$ atmosphere. Half of the specimens with final sintered density 7.00 ± 0.02 g/cm^3 were tested in the as-sintered condition, while, the other half after 1 hour tempering in air at 200°C.

It was found that the elimination of Ni, while feasible from the hardness, dimensional change and strength points of view, would inevitably reduce toughness substantially. The best composition that reaches and improves the current diffusion-bonded material properties is found to have 0.5%Mo – 0.7% Ni – 0.85% Cu and 0.85% Mn, stated Rampin.

Hoeganaes Corporation & GKN Sinter Metals

Brian W James and Kalathur S Narasimhan of Hoeganaes Corporation, USA, and Narsi Chandrachud of GKN Sinter Metals, Pune, compared the hardenability response of iron base prealloyed with 0.6% Mo (FL- 4205), Iron base diffusion alloyed with 0.5% Ni- 0.5% Mo (FD- 0105) and admixed hybrid powders.

It was found that prealloyed powder has a greater effect on hardenability than the same amount of that element that is diffusion alloyed or admixed. In lean alloy compositions, diffusion alloyed powders are suitable only for relatively small PM parts if the parts are to be subsequently heat treated. Hybrid alloys based on prealloyed powders that have molybdenum as their principal alloy addition provided flexibility.

The appropriate level of molybdenum may be selected according to the size of the PM part. Higher sintering temperatures and longer sintering times improved the hardenability of diffusion-alloyed and elementally admixed powders.

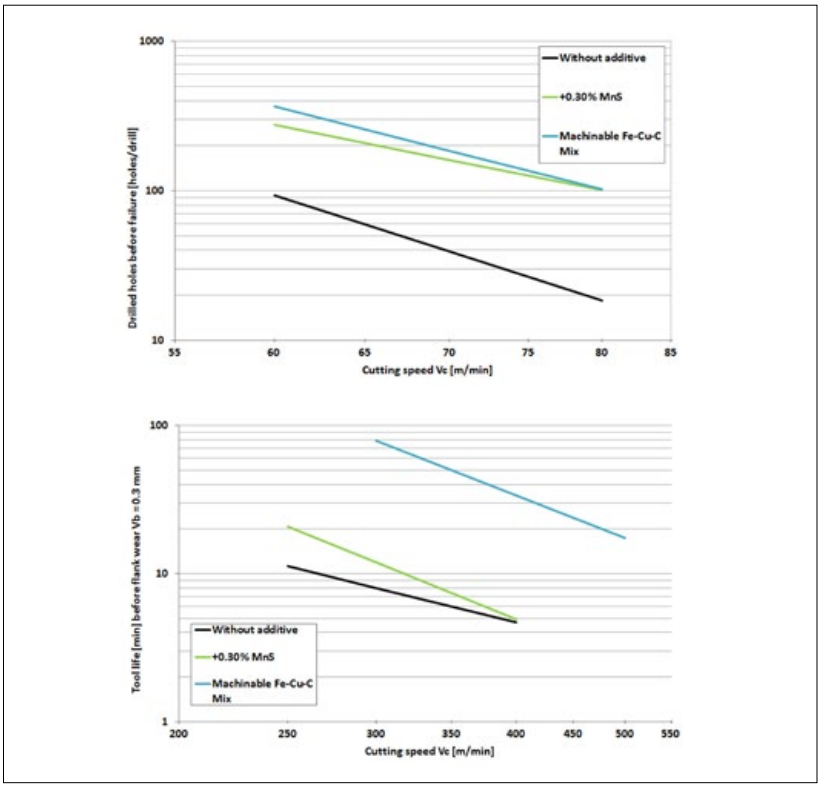

Fig. 10 (Top) Drilling machinability: AHC100.29 + 2%Cu + 0.8%C. Drilling parameters: Drill Ø3.5 A002, feed f = 0.06 mm/rev, cutting depth ap = 9.6 mm (blind), dry. (Bottom) Turning machinability: AHC100.29 + 2%Cu + 0.8%C, Turning parameters: Insert grade GC4215, feed f = 0.1mm/rev, cutting depth ap = 0.4 mm, dry. (Courtesy Höganäs AB)

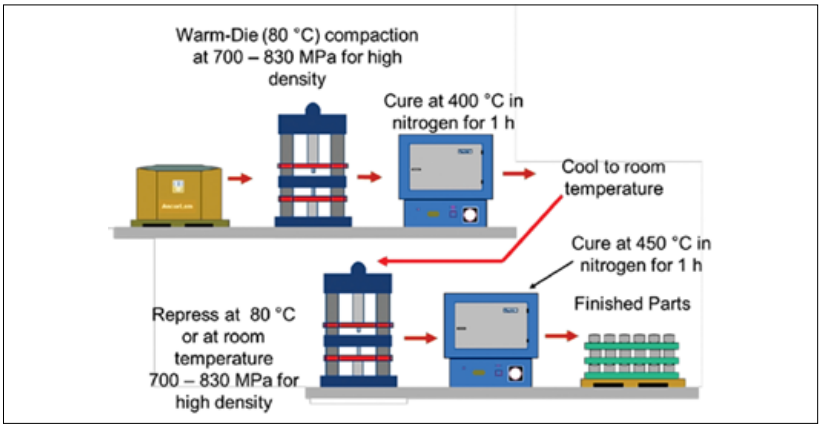

Fig. 11 The 2P2C process route outlined by Hoeganaes

Iron powder usage in electromagnetic applications has gained wider acceptance to replace ferrites operating at higher frequencies and lamination steels operating at lower frequencies. Kalathur S Narasimhan, Michael L Marucci and Francis Hanejko, Hoeganaes Corporation, USA in their presentation on "Effect of Particle Size and 2P2C Technology on the Soft Magnetic Properties of Composite Iron Compacts" studied in detail the effect of particle size distribution of screened pure iron powder on induction, permeability, coreless and Q factor (Fig. 11).

For applications of soft magnetic materials replacing lamination steels in motors and actuators the typical median particle size used is found to be 140 microns that can be processed to produce components with accept-

Fig. 12 The Zoz Simoloyer® shown top is used to process nanostructured materials (Courtesy Zoz)

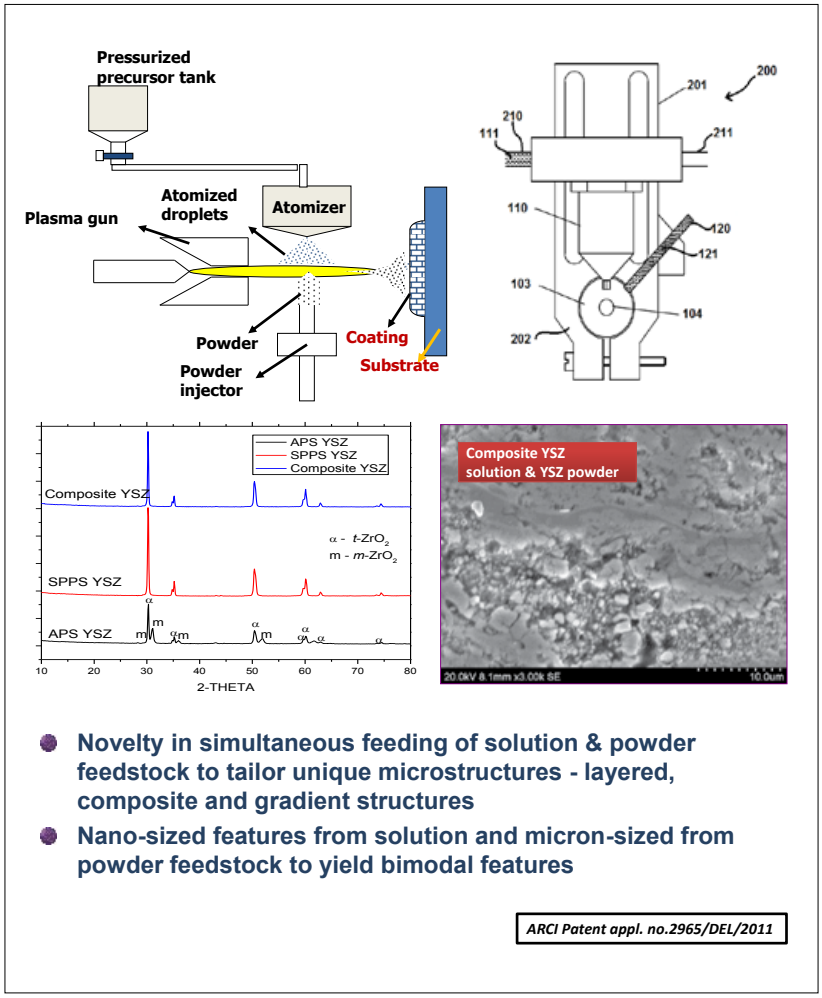

Fig. 13 The International Advanced Research Centre for Powder Metallurgy and New Materials discussed in detail the application of powders, suspensions and solution precursors to coat and engineer surfaces

able levels of induction and permeability. A process route called 2P2C allows for the formation of composite iron compacts to densities greater than 7.45 g/cm^3 thus increasing the composites' strength and magnetic performance.

Zoz Group

This year's Fellow of PMAI recipient, Prof. Dr. Henning Zoz, Zoz Group, Germany, presented a wide variety of applications for ultra fine and nano powders. The top priority, according to Zoz, is the materials requirement to convert, to store and to transport energy from alternate energy sources. However, materials consumption contradicts with limited resources, thus making recycling to be the other ultimate goal.

Both requirements lead to advanced materials processing with the utilisation of larger surface and finer structures created using the company's Simoloyer® "nanostructure making equipment".

Detailed examples were given, including the development of the first public footbridge using nanostructured high performance, high strength cement by Zoz/Dyckerhoff. Zoz also discussed Zentallium®, the group's super light-weight material stated as being half the cost of titanium and made by pressing, sintering and hot extrusion. Hydrolium®/H_2Tank2Go® hydrogen storage systems and the H_2-On Air project with EADS, Airbus, IFB *et al* were also discussed.

International Advanced Research Centre for Powder Metallurgy and New Materials

Shrikant V Joshi and G Sivakumar, International Advanced Research Centre for Powder Metallurgy and New Materials, India, discussed in detail the application of powders, suspensions and solution precursors to coat and engineer surfaces. This, stated the authors, will help to combat premature degradation of industrial components due to surface-related degradation modes such as wear, corrosion, oxidation, high heat flux etc.

Among the large portfolio of surfacing technologies that are available today, the use of different thermal spray variants has particularly proliferated in diverse industry segments by virtue of their ability to improve

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component performance, reliability and longevity through the appropriate tailoring of coatings as demanded by any given application. The past few years has focused on deposition of nanostructured coatings to further improve engineering properties. The use of nanostructured feedstock has been widely explored, with the earliest approach involving spraying conventional micron-sized spray grade powders comprising of agglomerated nano particles.

The relatively low temperatures and short residence times in Detonation Spray Coating (DSC) and High-Velocity Oxy-Fuel (HVOF) spray techniques, unlike in conventional atmospheric plasma spraying (APS), appear to offer significant promise for retaining the nanostructure in the starting feedstock. The advent of Cold Gas Dynamic Spraying (CGDS), characterised by maximum gas temperatures below about 600°C, has opened new vistas especially for metallic coatings.

The more recent efforts aimed at obtaining nanostructured coatings by the plasma spray route have consisted of either (a) introducing the materials to be sprayed in the form of a suspension of fine particles in a liquid (usually water or alcohol), which is fragmented and vapourised in the plasma plume, as in solution plasma spraying (SPS), or (b) spraying a solution of an appropriate liquid precursor so that gelation and pyrolysis occur in situ, as in solution precursor plasma spraying (SPPS).

Both SPS and SPPS were shown to hold promise to yield nanostructured coatings with superior properties as well as coatings with new chemistry, by virtue of molecular level mixing possible in solutions. The presentation discussed recent advances in the above thermal spray approaches and particularly illustrated resulting improvements in coating attributes. Apart from comparing the benefits of these methods, results from the authors' laboratory, which is equipped with all the above techniques, were discussed.

Developments in PM products and processes

A number of interesting developments in Powder Metallurgy processes and products were presented at PM-13 A number of these developments are highlighted below.

Soft magnetic powder materials

During PM-13 it was evident that there seems to be an increase in interest in magnetic products. Klaus Dollmeier and Ian W. Donaldson, GKN Sinter Metals, and Peter Sokolowski, Hoeganaes Corporation, presented a paper entitled "Soft magnetic powder metal materials and their processing for elevated strength requirements."

The authors stated that typical routes for the strengthening of ferrites in Powder Metallurgy, such as the addition of carbon, copper or through strain hardening, result in a decrease in soft magnetic properties and hence are not feasible alternatives.

A solution is found through the development of pre-alloyed Fe-Mo-P powders. The addition of P to Fe in order to stabilise the body centre cubic (BCC) structure and form a liquid phase at typical sintering temperatures (1120°C) resulted in rapid densification and pore rounding. This also led to grain growth and improves soft magnetic properties. The addition of molybdenum improved mechanical properties.

The effect of the prealloyed Mo with the 0.45 and 0.80 w/o P resulted in the permeability and coercivity both being improved for the same density at a drive field of 7958 A/m. At the higher density, the soft magnetic properties are improved (Tables 1 and 2).

Designation	Description	Base Iron	Phosphorus	Lubricant
Mix 1	FY-4500 Baseline	Ancorsteel 1000B	0.45 w/o	0.75 w/o Acrawax C
Mix 2	FL-4400 + 0.45P	Ancorsteel 85HP	0.45 w/o	0.75 w/o Acrawax C
Mix 3	FL-4400 + 0.45P Warm	Ancorsteel 85HP	0.45 w/o	0.6 w/o AncorMax 200
Mix 4	FL-4400 + 0.80P	Ancorsteel 85HP	0.80 w/o	0.75 w/o Acrawax C
Mix 5	FL-4400 + 0.80P Warm	Ancorsteel 85HP	0.80 w/o	0.6 w/o AncorMax 200

Table 1 Composition of mixes used for the investigation with phosphorus added as Fe_3P (Courtesy Hoeganaes)

Designation	Sinter Density (g/cm^3)	Drive Field (A/m)	Frequency (Hz)	μ_{max}	B_{max} (T)	H_c (A/m)	B_T (T)
Mix 1	7.29	7958	0.01	4463	1.57	95.5	1.21
Mix 2	7.31	7958	0.01	5052	1.56	79.6	1.19
Mix 3	7.5	7958	0.01	6767	1.64	71.6	1.29
Mix 4	7.24	7958	0.01	6235	1.53	71.6	1.21
Mix 5	7.39	7958	0.01	7024	1.6	71.6	1.21

Table 2 Soft magnetic properties at 1260°C sintering (Courtesy Hoeganaes)

Sinter hardened materials

Sinter hardening and the hardenability of sintered steels also seems to occupy substantial interest. "Improving the hardness of unalloyed iron PM parts by a new low temperature gas alloying process without rapid cooling" was presented by N. Gopinath, Fluidtherm Technology, India. This is a novel post sintering in-line (patent pending) process developed to produce high strength, low distortion unalloyed iron PM parts with a structure of hard transformation products eliminating subsequent heat treatment.

Hardness, wear, crushing strength and metallography of Fe-2% Cu samples of 6.8 and 7.2 g/cm^3 density with different carbon contents from several production scale trials were reported and compared to conventionally processed parts.

François Chagnon, Rio Tinto Metal Powders, Quebec, Canada discussed the factors affecting the properties of sinter hardened materials such as alloy and mix composition, sintering temperature, post-sintering cooling rate and tempering temperature. Powder hardenability, it was stated,

has a significant effect on tensile properties and apparent hardness of sinter hardened materials.

Based on detailed experimentation on the properties of specimens sintered from ATOMET 4601 and ATOMET 4701 Chagnon concluded that the choice of the base powder must take into consideration the size and section thickness of the part and the cooling efficiency of the sintering furnace. Improper selection of the base powder and carbon concentration can lead to only marginal gain on apparent hardness and tensile properties and can even deteriorate the latter if the amount of retained austenite becomes significant.

Crack formation during induction hardening

Philippe François, also of Rio Tinto Metal Powders, discussed the formation of cracks during induction hardening of PM parts. Induction hardening is a cost effective process to achieve high superficial hardness and residual compressive stresses. It is also particularly interesting for PM parts because the associated dimensional change is quite constant from part to part and thus predictable.

During this heat treatment, however, different volume changes occur due to thermal expansion and phase transformations. Because these volume changes mainly concern the surface and not the core of the part, stresses are induced in the part throughout the heat treatment. PM materials are generally more sensitive to crack generation during induction hardening because of their lower yield strength and much lower ductility compared to wrought steels.

Although an accurate stress calculation during induction treatment requires a very complex modelling, a simplified description of the stress variation at the surface during induction hardening was considered and was validated by a comparison with published data on wrought steels. Two different PM case studies (sprockets) were reviewed and crack generation was explained using the model.

The S. L. N. Acharyulu Memorial Lecture

At this year's conference the S. L. N. Acharyulu Memorial lecture was delivered by J. Viplava Kumar, Dean Research and Professor of Metallurgical and Materials Engineering at MGIT Hyderabad. He gave a presentation on the "Secrets of particle deformation and contact flattening during powder compaction."

During the compaction of a powder, externally applied pressure is transmitted through inter particle contacts inducing particle deformation and contact flattening. The extent of flattening of individual particles is governed by the hardness of the material of the powder and the laws of pressure transmission in powders. An understanding of the phenomenon of pressure transmission in powders and the resulting geometric responses of individual particles is essential for predicting pressure dependence of densification of powders.

Extensive experimental studies on the pressure dependence of contact flattening in "single-sphere compacts, single-layer compacts" model compacts consisting of randomly packed equal sized ductile spheres, and compacts consisting of spheres of various sizes have established that a constrained powder transmits externally applied pressure uniformly in all directions, like a confined fluid.

Uniform pressure distribution implies equalisation of pressure on all the load-bearing elements (particles) of the system. In order to ensure equal pressure on all particles, each particle receives and transmits load in proportion to its own surface area. Furthermore, the sum of the contact areas of any given spherical particle on either side of an arbitrarily chosen equatorial plane is equal (action-reaction equalisation). An implication of these results is that during compaction, each pore section of a powder shrinks in proportion to its own size (Fig. 14).

"During the compaction of a powder, externally applied pressure is transmitted through inter particle contacts inducing particle deformation and contact flattening"

Multilevel closed loop servo hydraulic sizing presses

Jean-Marie Pierson, Dorst Technologies GmbH & Co, Germany, discussed the recent development of multilevel closed loop servo hydraulic sizing presses. Sizing presses are used for several operations such as the minimising of tolerances, the smoothening of surfaces, increasing density and for bevelling.

With tolerances of large multilevel PM parts getting smaller and with higher quality expectations from the final customers, PM part producers are looking for improved possibilities to size their parts. Beside the well-known sizing presses actuated with pure mechanical motion, and following a generation of hydraulic sizing presses without feedback of information during the movements, a new technology has been recently

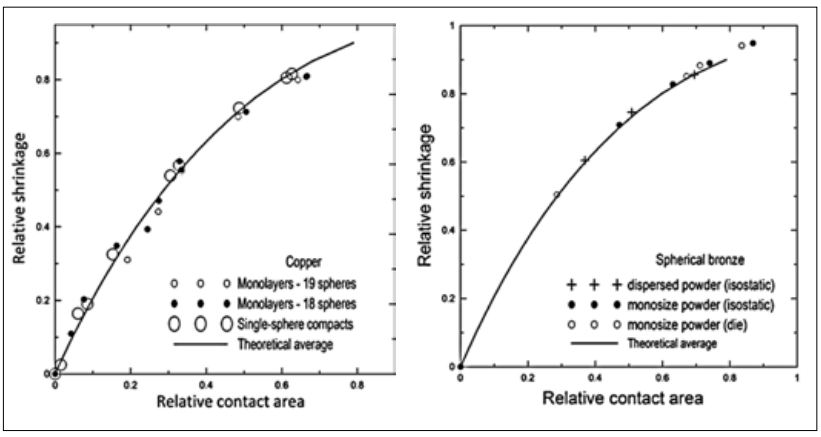

Fig. 14 Relative shrinkage of copper and spherical bronze powders

Fig. 15 The TPA 1200/3 K sizing press from Dorst Technologies

Fig. 16 Helical Tool Box for TPA250/3 from Alvier AG PM-Technology

introduced in the market. This paper reviewed sizing technology in general, including the different generations of sizing presses and the most recent development with closed loop controlled movements (Fig. 15).

The compaction of helical gears

Ekkehard Gutowski, Alvier AG PM-Technology, Switzerland, discussed the intricacies involved in the compaction of helical gears. The applications for helical gears are permanently increasing and PM is the right technology to produce such helical gears if certain challenges are taken care.

The helical movement of the punches and the die lead to special design requirements for helical gears and they are not free from limitations. Conventional drive systems for the upper punch tend to be inaccurate. Alvier's helical gearbox, stated the author, guarantees a smooth entry of the rotating upper punch into the die. The mechanical system converts the linear movement of the press into the required rotation. With its modular design it can provide high precision and a universal use without limitations on the press functions (Fig. 16).

Powder forging for high performance con-rods

Edmond Ilia, Metaldyne LLC, USA, has been crusading for some time on the advantages of Powder Forging (PF) as it represents a cost effective technology to manufacture connecting rods in high volume production conditions. Higher performance, superior raw material utilisation and lower total cost of the finished machined and assembled product are the main reasons why the use of PF connecting rods has significantly increased in the last thirty years, taking away market share from drop forged connecting rods.

In order to meet the increased performance requirements of the future generations of diesel and gasoline engines, new high strength PF materials, such as HS150, HS160, and HS170, which successfully compete with wrought steels, were developed and introduced in production with excellent results. Among them, HS170M is currently used to manufacture connecting rods for several high performance engines. These connecting rods not only have a higher strength, but less variation in their mechanical properties.

Mechanical properties of PF connecting rods manufactured with HS170M and connecting rods manufactured through drop forging with micro alloyed steels were evaluated side by side. The results showed that PF connecting rods manufactured with HS170M are stronger than their drop forged counterparts manufactured with newly developed modified versions of micro alloyed steels, are easier to machine and split crack, and represent a cost effective way to manufacture this important high reliability automotive component (Fig. 17).

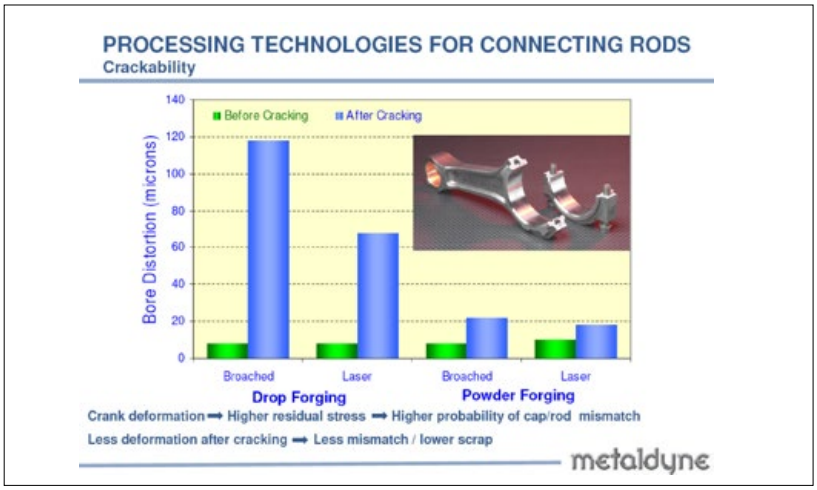

Fig. 17 Processing technologies for connecting rods (Courtesy Metaldyne LLC)

Pre-conference events reveal potential of Powder Metallurgy in India

Organised to coincide with PM-13 were a number of notable pre-conference events. These included a "Power of Powder" seminar organised by Höganäs and a panel discussion hosted by Battelle India.

Power of Powder-2 Seminar

PM powder producer Höganäs organised a "Power of Powder-2" seminar on 6th February 2013 at the Hotel Westin, Pune. The event attracted around 150 delegates from automotive and non automotive OEMs, Tier 1 suppliers and component manufacturers.

The seminar began with a presentation from Srini V Srinivasan, CEO of Höganäs India, who after welcoming participants explained how Höganäs India is actively encouraging PM entrepreneurs whilst also helping existing components manufactures with new grades of powders and component technologies.

The versatility of Powder Metallurgy technology and its global nature was discussed in detail by Hans Söderhjelm, Vice President, Marketing & Product Development, Höganäs AB Sweden.

Dr Anders Flodin, a gear expert at Höganäs AB Sweden, illustrated the design and development process in adapting a Smart Car to use PM gears, highlighting the fact that PM offers lighter and stronger gears. The car, he stated, was up and running with over 120,000 km on the odometer, having a goal of 200,000 km. Reverse engineering had indicated that all gears can be made with Powder Metallurgy except for those cut on shaft, and the redesign shows an 8-20% weight reduction depending on the gear. The energy savings during acceleration with the light weight gear design are around 6%, added Flodin.

An overview of Japanese PM technology was presented by Dr Yoshinobu Takeda of Höganäs Japan, with overviews of the Korean and Chinese markets presented by Paul Skoglund, Höganäs AB.

The status and overview of the North American Powder Forged (PF) con rod business was discussed by Dr Edmund Ilia of Metaldyne LLC. As can be seen in Fig. 18, the use of powder forging for the manufacture of automotive con rods can result in considerable cost savings. Net shape forming improves material utilisation by up to 40% compared with conventional forged steel and can offer improvements in fatigue strength, stiffness and weight variation.

Nagarjuna Nandivada, Höganäs India, then presented an overview of PM technology in India (Fig. 19). Following analysis of the production statistics of two, three and four wheeled vehicles in India, Nandivada had enumerated the current level and type of components produced by the Indian PM industry. Nandivada predicted that the next level of PM components would include higher strength gears, helical gears, PF con rods, wear components, assembled camshafts with PM cam lobes and stainless steel flanges for exhaust systems etc.

Nandivada suggested that future contributions from Höganäs India could be in the areas of special products for wear alloys and stainless steels, capability for the manufacture of prealloyed Ni-Mo materials, the development of cost effective lean alloys, machinable clean mixes, bonded mixes, low AD atomised iron powders and last but not the least technical services and PM promotion.

Eckart Schneider, Global Marketing Manager PM Components, Höganäs AB, Sweden, described the "Power of Powder" concept as providing value added services to customers and OEMs, and helping to identify and develop new business opportunities. The aim, stated Schneider, is to improve the competitiveness of PM versus other manufacturing processes, whilst at the same time reducing time, cost and risk for new PM applications and process developments.

Auto application trends and opportunities for PM were discussed by Thomas Schmidtseifer of Höganäs Germany. Camshafts assembled from PM components, stated Schmidtseifer, are almost 50% lighter than those manufactured from

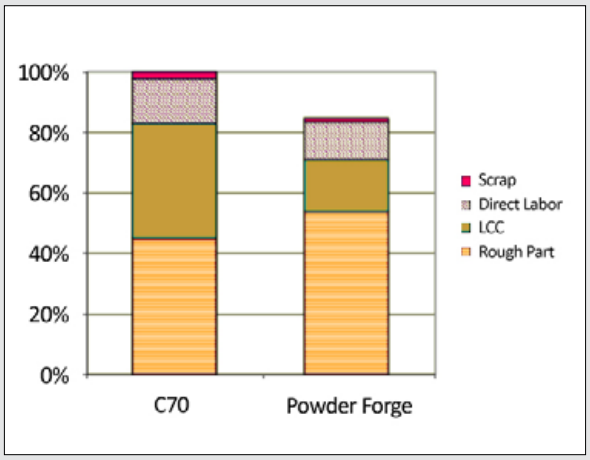

Fig. 18 Cost comparison of the processing technologies for connecting rods (courtesy Metaldyne LLC)

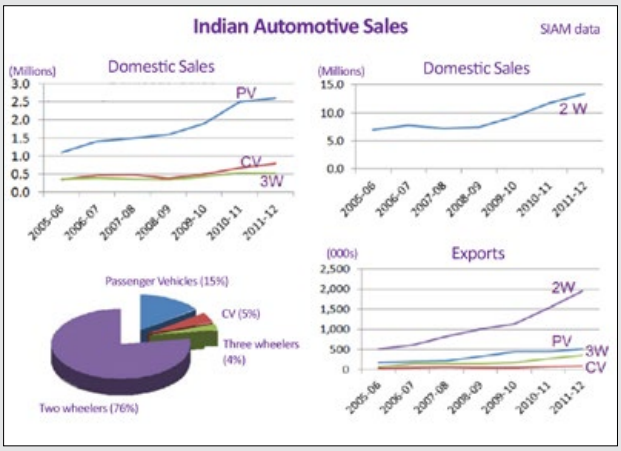

Fig. 19 Automotive sales in India (courtesy Höganäs)

Fig. 20 Shalendra Porwal, MD & CEO Battelle India, and Dr Abhay Firodia, Chairman Force Motors

Fig. 21 The panel included (left to right) S Panse, T R Ramamohan, Sunil Earath, D Varshney and V Srinivasan

conventional technologies, with lower inertia and emissions. Schmidtseifer identified the use of PM variable valve timing (VVT) components in hydraulic systems and electrical systems of the engine, along with current and future trends of PM in manual transmissions. Various initiatives being undertaken for the use of PM in electrical drives were also discussed.

A presentation by Jean-Marie Pierson, Dorst Technologies, looked at advances in compaction technology in the areas of metal powders, technical ceramics, magnetic materials, hardmetals and special materials. Pierson discussed the applications of high speed mechanical presses from 6 to 450 tons, hydraulic presses from 15 to 2000 tons, electric presses from 15 to 160 tons and sizing presses of various tonnages. The latest developments illustrated included helical part sizing, multilevel closed loop control sizing, synchronizing hubs with 15 strokes per minute, a high speed adaptor transfer system for large presses and new applications such as interconnector plates for fuel cells.

Tooling solutions were discussed by Peter Rauch, CEO of Alvier PM Technology. A detailed presentation covered various tooling options and included the special tooling developed for the Höganäs PoP Center and the latest achievements in helical gear compaction.

The recent developments in sintering and heat treatment technologies to achieve high densities and hardness were discussed by Narasimhan Gopinath, Managing Director, Fluidtherm, India. The seminar ended with a presentation from Deepak Grover of Höganäs India, discussing the various ways in which Höganäs can provide 'PoP' support to the PM industry.

Innovation and product development in India: Particulate materials

A second event, also held on February 6th, was hosted by Battelle India and consisted of a panel discussion on "Innovation and Product Development in India - with special focus on particulate materials." More than 40 CEOs and R&D heads from various organisations associated with particulate materials attended the meeting at the Hyatt Regency in Pune.

Battelle India MD and CEO, Shalendra Porwal, showcased their R&D expertise and discussed the utility of a multi client approach. Battelle India is a nonprofit organization set up to bridge the gap between academia and industry. Porwal discussed Battelle's model of contract R&D as a way to bring faster innovation and product development. Battelle protects the client's interest by maintaining secrecy, stated Porwal.

Dr Abhay Firodia, Chairman Force Motors, was the chief guest for the evening. He talked about the need for carrying out cost-effective R&D which has use in a final product. He emphasised the importance of going from concept to incubation and finally industrialisation. He discussed how products in India should be developed keeping in mind the requirements of India, particularly rural areas. Battelle has a great role to play in this field by not only solving problems but also by instilling the importance of carrying out research with an end result in mind.

Prof Ramamohan Tallapragada, retired professor IIT Bombay, discussed the need for decentralising R&D. He talked about the product development chain in the particulate material industry and challenges faced by the industry.

Srini V Srinivasan, CEO of Höganäs India, Deepak Varshney, Chairman, Star Group of Companies, S. Panse (retired GM Materials Technology Tata Motors) and Prof Ramamohan Tallapragada served as panellists for the event, representing the various areas of particulate materials namely powder production, manufacturing of components and end use of powder metallurgical parts. Battelle India's VP Operations, Sunil Earath, moderated the panel discussion. Battelle India scientists discussed R&D requirements and needs with representatives from various organisations.

It was an exciting evening that showed great promise for future R&D collaborations in the field of particulate materials. The event was followed by a dinner hosted by Battelle India.

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JPMA award winning parts offer an insight into Powder Metallurgy technology in Japan

The winners of the Japan Powder Metallurgy Association (JPMA) 2012 Powder Metallurgy Awards highlight the capabilities of PM and demonstrate the continuing advances of Japan's PM industry. Many of the winners are evidence of the continuing potential for PM applications in the automotive industry.

Development Prize: New Design

Variable valve timing parts on the exhaust side for eco-friendly car

Diamet Corporation received an award for the development of a rotor and housing for the variable valve timing system of an eco-friendly car.

The design required high precision components offering weight savings and cost reductions (Fig. 1).

The combination of the rotor and the housing was designed to avoid drilling holes for setting springs. Tight tolerances between the rotor and the housing were achieved, resulting in a sealant free system. Blind holes on the rotor were formed by compaction, which resulted from improved powder flow and optimised tool design and material.

Sintered bearings for the poppet valves in an exhaust gas recirculation system

Diamet Corporation also received an award for the development of sintered bearings for the poppet valves in an exhaust gas recirculation (EGR) system (Fig. 2).

The original bearing was made from graphite in order to endure high temperature (250°C) tribological properties and was machined out for the inner asymmetric shape to inhibit valve rotation.

Diamet has developed a new PM material to replace the graphite bearings. The Cu-Sn-C material has a high carbon content of more than 6mass% to satisfy the high temperature tribological properties. The microstructures of the material consist of Cu-Sn matrix and uniformly dispersed graphite phase. The graphite phase also seals pores, which results in preventing oxidation.

Powder Metallurgy offers a machining free production process, with the guide part of the asymmetric inner hole shaped by sizing.

Torque converter utilising CNC compacting techniques

Sumitomo Electric Industries, Ltd. received an award for the development of a turbine hub used for a torque converter of an automatic transmission (Fig. 3).

CVT production has been increasing

Fig. 1 Variable valve timing parts for eco-friendly car offering weight savings and cost reductions (Courtesy JPMA)

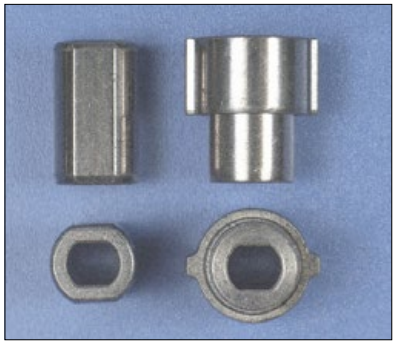

Fig. 2 Sintered bearings for the poppet valves in an exhaust gas recirculation system (Courtesy JPMA)

Fig. 3 This torque converter is manufactured utilising CNC compacting techniques (Courtesy JPMA)

Fig. 5 These sintered support parts for a parking shift unit are used in an automotive CVT (Courtesy JPMA)

Fig. 7 Low noise oil impregnated bearings for fan motors in super-slim laptops (Courtesy JPMA)

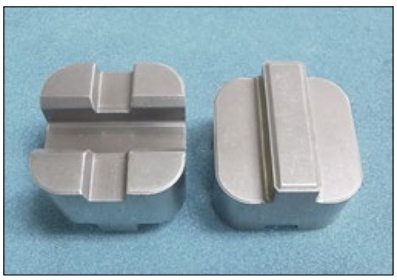

Fig. 4 The sintered coupling requires high strength and wear resistance properties (Courtesy JPMA)

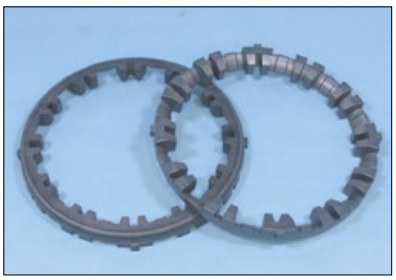

Fig. 6 This part is used in a centrifugal clutch system for automatic motorcycles (Courtesy JPMA)

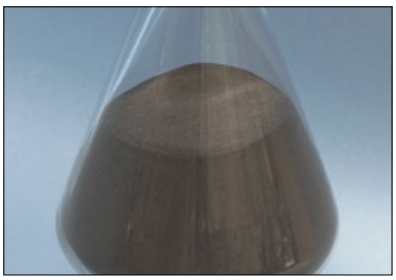

Fig. 8 A segregation-free mixed powder to improve drilling performance of iron-based sintered parts (Courtesy JPMA)

for small vehicle applications, offering better transmission efficiency at a low speed range. However, for large vehicles requiring a larger output, automatic transmissions are preferred. The use of forged turbine hubs in automatic transmissions become the main choice due to the need for high strength, large, complicated shapes.

This sintered turbine hub, developed by Sumitomo Electric Industries, utilises CNC compacting technology and sizing techniques. The product has a complex shape incorporating a large, thin, flange with 24 rivet holes and inner spline with step.

The turbine hub, successfully produced by the Powder Metallurgy process, offers a lower cost alternative to that produced by forging.

Sintered coupling for the balancer in a clean diesel engine

Diamet Corporation received an award for the development of this coupling for the balancer in a clean diesel engine (Fig. 4). The high strength, wear resistance part works as a connection between crankshaft and balancer, where high precision is required for assembly.

In order to obtain a cost advantage to wrought steels the part is produced without machining. High precision is achieved by optimum tool design and material based on FEM analysis, and by optimisation of compacting conditions for the improvement on the density distribution. A Fe-Mo-C system steel was selected for the material of the part.

The Powder Metallurgy process allows for the net shape mass production of this high precision component.

Parking shift support parts in a CVT system

Hitachi Chemical won a prize for the development of these support parts for a parking shift used in an automotive CVT (Fig. 5).

The design eliminates the need for certain existing parts, allowing for a more compact unit

The prevention of cracks during compaction was managed by improvement in tooling rigidity. Heat treatment was optimised in order to secure the dimensional accuracy.

The PM process allows for a design that reduces the total number of parts used in the unit, offering weight and cost savings.

Component of a lightweight centrifugal clutch

Hitachi Chemical also received an award for the development of a centrifugal clutch part for automatic motorcycles (Fig. 6). The component required a high level of accuracy and wear resistance, whilst being lightweight for improved fuel economy and offering a reduction in cost.

A high dimensional accuracy resulted from suppressing the variation in density distribution, analysing the filling method of material powder, feeder and compacting conditions, optimizing sintering and sizing conditions and applying a steam treatment instead of normal carburizing.

The final design allows for mass-production of the lightweight centrifugal clutch parts, whilst meeting the customer's accuracy, wear resistance, and cost reduction requirements.

Development Prize: New Materials

Low noise oil impregnated bearing for fan motors in super-slim laptops

The material developed by Porite Corporation is used for producing low noise bearings for the fan motors in super-slim laptop computers (Fig. 7).

As the laptop becomes thinner and lighter so does the fan motor in it. The thinner motor means shorter length and higher loads per unit area of the bearing supporting the shaft. As a result the oil film strength of the bearing becomes insufficient and can

cause increased noise levels.

To prevent high frequency noise caused by iron in the material, Porite developed a bronze based powder with a reduced tin addition.

The resulting material allows for low noise and low cost oil impregnated sintered bearings to be produced. In the future, Porite expect that this bearing material can also be applied to the cooling fan of home LED lamps.

Development Prize: New Powder

Segregation-free mixed powder to achieve a sintered material with excellent drilling performance

JFE Steel Corporation have developed this segregation-free mixed powder in order to improve drilling performance of iron-based sintered parts (Fig. 8).

Conventionally a sulfurization treatment is applied to the part which has many holes, such as a shock absorber piston. However, carbon disulfide used in the sulfurization treatment is a substance subject to Pollutant Release and Transfer Register (PRTR) regulations, and as such an alternative method of sulfurization treatment is desired.

The material from JFE, which has a newly developed machinability aid, achieved excellent drilling performance with reduced cutting forces by decreasing the shear strength in shear deformation of chips.

As a result, not only is it possible to replace the sulfurization treated material with this new product, it also offers significantly improved tool life.

Effort Prize

Precision cam sprocket with sensors for an idle reduction system

Sumitomo Electric Industries, Ltd. received an Effort Prize for this cam sprocket with sensors used in a vehicles idle reduction system (Fig. 9).

The introduction of the idle reduction system into vehicles is expanding rapidly due to the need for improved fuel economy.

Three sensors were formed on the face of the large size sprocket and weight reduction was achieved by adding holes and adding grooves in the opposite face.

The newly developed sintered sprocket has successfully started mass production.

Valve seat material with higher wear resistance

Fine Sinter received an Effort Prize for development of this material for manufacturing valve seats used in modern high performance automotive engines (Fig. 10).

A valve seat material offering higher wear resistance is required for use in the latest high performance automotive engines. There are two approaches to obtain high wear resistance: one is adding and scattering hard particles in the material, and the other is generating oxide on the material surface to prevent the adhesive wear originating from the contacts with the valve material.

The approach of adding hard particles, however, has become disadvantageous to oxide formation due to its higher costs and incompatibility with the high performance engines working in non oxidizing environments.

Fine Sinter achieved high wear resistance by adding a small amount of rare earth metal to the existing Mo-Co wear resistant hard particles to disperse the stabilized rare earth oxide in the particles.

This technology produced higher wear resistance than that of previous materials and enabled a reduction in costs as well as the amount of added wear resistant hard particles.

Sintered brake lining for high-speed trains on Japan's regional rail network

A further Effort Prize was presented to Fine Sinter for the development of a material used in the brake linings of high-speed trains (Fig. 11).

Synthetic resin is conventionally used for brake linings on high-speed trains running on Japan's regional rail network. However, as the maximum speed of these vehicles is further increased, this material will reach the limit of its performance. Thus it has been necessary to adopt sintered brake linings, similar to those used in Japan's bullet trains.

However, the requirements of trains on the regional rail network differ from that of the Bullet Train system. The braking distance is shorter than bullet trains and requires the lining to be pressed against the brake with a larger force, but the maximum speed of the regional trains is lower.

Fig. 9 This cam sprocket with sensors is used in a vehicles idle reduction system (Courtesy JPMA)

Fig. 10 The new valve seat material offers higher wear resistance for use in high performance engines (Courtesy JPMA)

Fig. 11 These brake linings designed for use on high-speed trains use a Cu-Sn-Ni-based material (Courtesy JPMA)

To address this, Fine Sinter applied Cu-Sn-Ni-based material instead of the conventional Cu-Sn-based material to ensure strength at the temperature reached when braking. In addition, they optimised the amount of lubricant added in order to obtain a stable coefficient of friction at the beginning of brake application and immediately before stopping. This was achieved by increasing the amount of lubricant.

The resulting sintered friction material, offering a stable friction coefficient, has now been adopted as the brake lining for high-speed trains running on Japan's regional rail network.

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Powder metallurgy is leading the way.

Novel routes to high density ferrous Powder Metallurgy compacts

The powder metallurgy (PM) industry is continuously striving to increase the final densities of its ferrous products in order to improve mechanical and dynamic properties, or in the case of soft magnetic parts their magnetic performance. Bernard Williams reviews two papers presented at the PM2012 World Congress, Yokohama, Japan, October 15-18, by Japanese researchers at Toyota Motors and Aida Engineering which describe novel approaches to achieving high density ferrous PM products.

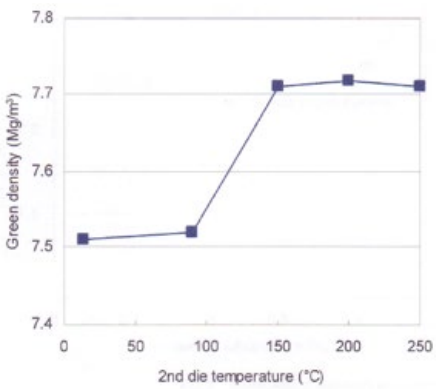
High density compaction method for soft magnetic composites (SMCs)

Kazuhiro Hasegawa and his colleagues at Aida Engineering Ltd in Sagamihara, Kanagawa, described a two-step compaction process used to produce iron powder compacts for soft magnetic cores having green densities in excess of 7.7 g/cm³. The authors used Somalloy 700 SMC grade iron powder produced by Höganäs AB, where each powder particle is coated with an insulating layer, mixed with 0.4 wt% Kenolube pressing lubricant.

The powder mixture was compacted into ring shaped compacts at a high compacting pressure of 980 MPa followed by pre-heating the compacts to 150°C. The heated compacts were subject to a second 'warm pressing' step also at 980 MPA in a die heated to the same temperature to achieve a green density of not less than 7.7 g/cm³. The second die for warm pressing has a clearance of 0.2 mm to allow for easy loading of the compact. The compacts are finally heat treated at 520°C for 10 min in air.

As can be seen in Fig. 1 the temperature of the second die and the pre-heating of the compact is critical to the increased density achieved in the second warm pressing. This is due to the pressing lubricant in the 1st pressed compact melting during pre-heating above 130°C with the liquid phase reducing frictional slip resistance between the powder particles during warm pressing, and thereby helping the SMC iron powder particles to fill in the pores remaining in the compact after first compaction.

Additionally, the molten lubricant which is exuded from within the compact during pre-heating to 150°C creates a lubricating film on the surface of the compact for die wall lubrication, whilst at the same time reducing the total wt% of lubricant in the compact to as little as 0.1%. Hence the sharp increase in green density in the second warm pressing at 150°C. The 0.2 mm die clearance in the warm pressing step was critical in allowing



Amount of lubricant	0.4 wt%
1st compacting pressure	980 MPa
2nd compacting pressure	980 MPa
Clearance	0.2mm

(Pre-heating temperature of the 1st green compact is the same as the 2nd die temperature)

Fig. 1 Relationship between 2nd compaction die temperature and green density [1]

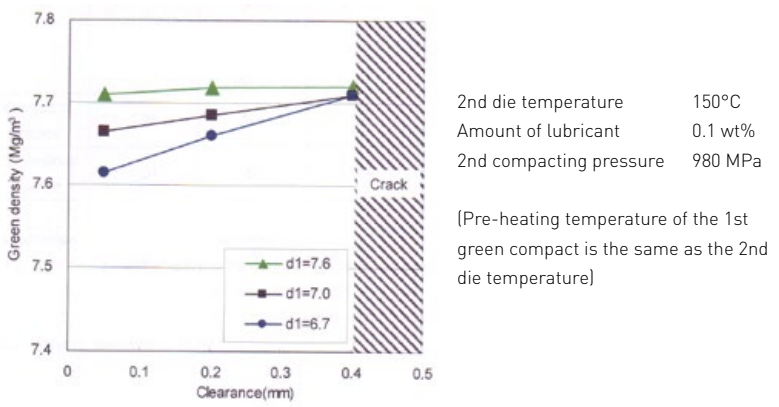


Fig. 2 Relationship between die clearance and green density in second pressing step. (d1: green density after 1st compaction)

	Density (Mg/m³)	Radial crushing strength (MPa)	Magnetic flux density (H=10kA/m) (T)	Coercive force (A/m)	Resistivity (μΩm)	Iron loss (B_{max}=1.0T, f=400Hz) (W/kg)
Developed method	7.75	105	1.73	187	1990	37
Conventional method	7.51	80	1.56	210	400	44

Table 1 Mechanical and magnetic properties of SMC magnetic core ring samples (heat treated at 520°C) [1]

powder particle sliding and to produce SMC compacts without cracks (Fig. 2).

The researchers compared the properties of the new two-step method with the conventional method of single pressing at 980 MPa of SMC powders containing 0.4 wt% lubricant at room temperature to reach a green density of 7.51 g/cm³. It was found that the higher density using the newly developed two step compaction method increased the radial crushing strength and magnetic flux density.

Resistivity was increased by about 5 times compared with the single compaction step conventional method which the authors state is an indication that there was no detachment of or damage to the insulating film on each iron powder particle during the first or second pressing stages (Table 1).

The researchers also used Somaloy 110i SMC iron powders, amorphous powders and Fe-6.5%Si to produce magnetic cores by the two-step compaction method and compared the densities achieved with the conventional single pressed method. In all cases increase in green densities was achieved along with improved magnetic properties. Somaloy 110i is a finer coated SMC iron powder produced by Höganäs AB and has been optimised for higher frequencies applications ranging from 10 to 100 kHz, such as inductive components in boost converters for electric and hybrid electric vehicles.

Influence of long time sintering on density of Fe-Mn-Si-C steels

An alternative approach to achieving high density in ferrous PM compacts is to combine high pressure compaction (HPC) with long time sintering (LTS). Toshitake Miyake and his colleagues at the Toyota Central R&D Laboratories Inc., Nagakute, Aichi, took this approach for an Fe-Mn-Si-C Powder Metallurgy steel having a final sintered density of 7.5 g/cm³ . The authors stated that the new PM ferrous material is intended as an alternative material to the commonly used but difficult to recycle PM Fe-Cu-C alloys.

The authors used a Höganäs ASC100.29 water atomized iron powder mixed with 2wt% of a prototype fine (D50:1.1 μm) Fe-Mn-Si-C powder (designated FeMS), and 0.8wt% natural graphite powder. The average composition by wt% of the mixed powder was Fe-1.32%Mn-0.4%Si-0.82%C. High pressure warm compaction (HPC) up to 1176 MPa with die wall lubrication (lithium stearate) was used to produce cylindrical specimens having a green density of 7.2 g/cm³. The green compacts were sintered in pure nitrogen at 1423K for up to 360 ks.

Compaction and sintering conditions are shown in Table 2, and Fig. 3 shows the influence of HPC and LTS

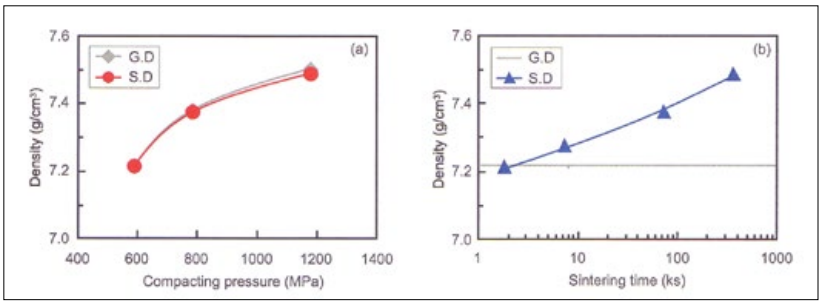


Fig. 3 Green and sintered densities of (a) HPC and (b) LTS specimens [2]

Densification process	Compaction			Sintering			
	Method (Lubricant)	Die temperature (K)	Pressure (MPa)	Temperature (K)	Time (ks)	Atmosphere	Cooling rate (K/s)
HPC	Warm compaction using die wall lubrication (LiSt.)	423	588, 784, 1176	1423	1.8	Pure N_2	0.8
LTS			588	210	1.8, 7.2, 72, 360		

Table 2 Compaction and sintering conditions used to produce the high density Fe-Mn-Si-C sintered alloy [2]

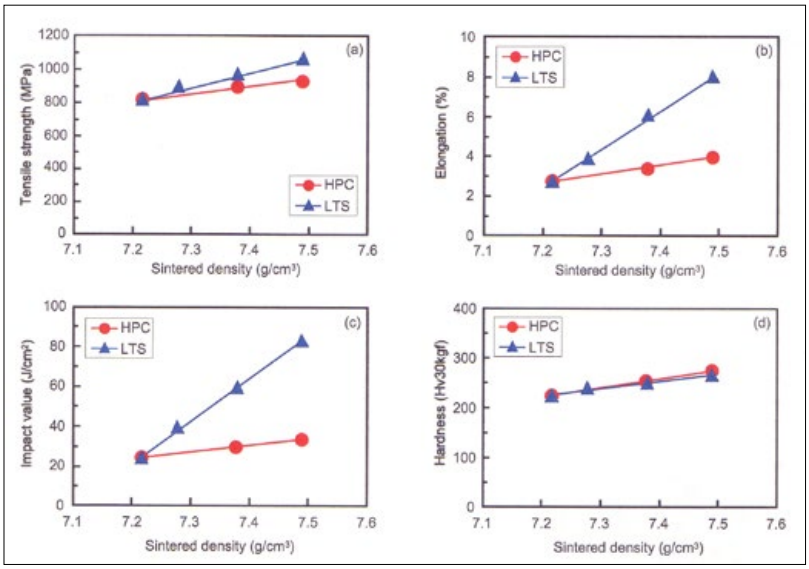


Fig. 4 Relationship between sintered density and mechanical properties of PM Fe-Mn-Si-C alloy [2]

on green and sintered densities which reached 7.5 g/cm³ when sintering time was 360ks after HPC. The increased density was attributed to shrinkage of the compacts during LTS of around 1% in the diametrical direction and around 1.3% in thickness direction.

There was however a significant increase in the mechanical properties of the high density PM Fe-Mn-Si-C steels after HPC and LTS with particularly good elongation and impact strength values at 7.5 g/cm³ (Fig. 4). A key reason for the improvement in properties is the change in pore morphology brought about through LTS. The authors stated the maximum pore length decreased with increasing both the compacting pressure and the sintering time, and the spheroidization of the pores increased markedly with increasing sintering time giving the much improved elongation and impact values.

The microstructure in the sintered Fe-Mn-Si-C specimens consisted mainly pearlite independent of compacting pressure or sintering time, but the distribution of Mn and Si was more homogeneous after LTS. However, the homogeneous microstructure was considered to have only a slight effect on mechanical properties.

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[1] 'Development of High Density Compaction Method' by K Hasegawa, Y Hirai, S Morinaga, Aida Engineering Ltd, Kanagawa, Japan. Presented at the PM2012 World PM Congress, Yokohama, October 15-18, and published in the Congress Proceedings by JPMA/JSP&PM, Japan

[2] 'Influence of Densification Processes on Microstructure and Mechanical Properties of Fe-Mn-Si-C Sintered Steels' by T. Miyake, N Matsumoto and M Kondoh, Toyota Central R&D Laboratories Inc., Nagakute, Aichi, Japan. Presented at the PM2012 World PM Congress, Yokohama, October 15-18, and published in the Congress Proceedings by JPMA/JSP&PM, Japan

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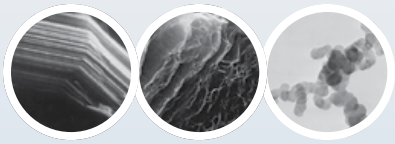

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