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AUTUMN/FALL 2012

POWDER METALLURGY REVIEW

TRENDS IN HIP TECHNOLOGY

DEVELOPMENTS IN PM ALUMINIUM

MPIF AWARD WINNING PARTS

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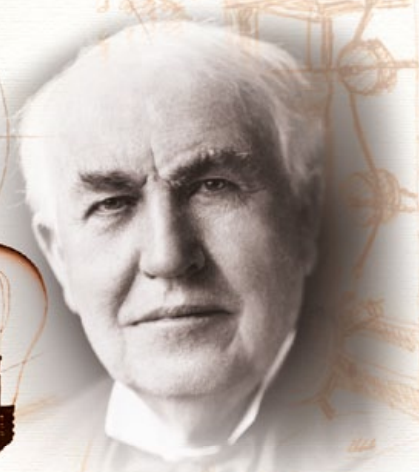
Like many exceptional eminent innovators of the past, our pioneering metallurgists at **Hoeganaes Corporation** continue to set increasingly higher benchmarks in the field of powder metallurgy.

We continue to **lead innovation in technologically advanced metal powders and processes** that meet customers' ever-increasing demands for high performance materials solutions. These new processes have been a major factor in establishing powder metallurgy (PM) as the **fastest growing metal forming process in the world**. PM products we've developed with these processes allow fabricators to produce parts with greater strength, higher densities, enhanced dimensional stability and with more complex geometries than ever before.

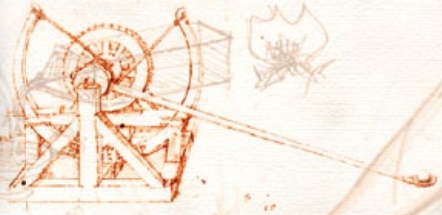
"Genius is one percent inspiration and ninety-nine percent perspiration A 'genius' is often merely a talented person who has done all of his or her homework."

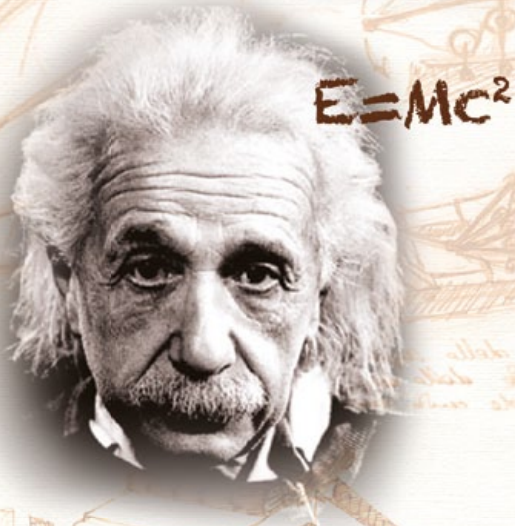
— ***Thomas Alva Edison*** *(1847 - 1931)*



"It had long since come to my attention that people of accomplishment rarely sat back and let things happen to them. They went out and happened to things."

— ***Leonardo da Vinci*** *(1452 - 1519)*





"Imagination is more important than knowledge. Knowledge is limited. Imagination encircles the world."

— ***Albert Einstein*** *(1879 - 1955)*

"The combined results of several people working together is often much more effective than could be that of an individual scientist working alone."

— ***John Bardeen*** *(1908 - 1991)*

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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

A new magazine for the PM industry

Welcome to the first issue of *Powder Metallurgy Review*, a new quarterly magazine for the PM industry from Inovar Communications Ltd.

This new publication comes on the back of our highly successful weekly *ipmd.net* e-newsletter, launched in October 2010 and now sent to more than 7000 PM professionals. Despite the success of our e-newsletter in delivering PM industry news "as it happens", we have launched this title in response to feedback from numerous industry professionals who, whilst appreciating the advantages of a weekly e-newsletter, also wish to have such information on the PM industry in a format that they can keep, either digitally or in print, for future reference.

Powder Metallurgy Review will therefore be available in both print and digital formats, bringing together news and technology developments from the ipmd.net website plus additional exclusive content. We will specifically focus on developments in the global press and sinter PM industry, including ferrous and non-ferrous components, hard materials, PM high alloy steels, PM superalloys, diamond tools and sintered magnets, as well as HIP/CIP and powder forging.

As with its sister publication *Powder Injection Moulding International*, our mission is to not only provide relevant coverage of the industry and its many players, but to present Powder Metallurgy in a positive light, as the dynamic, modern and successful advanced metal forming process that it is.

This launch issue will be distributed from our stands at Euro PM2012, Basel, and the PM2012 World Congress and Exhibition, Yokohama. From 2013, it will be published four times a year (Vol. 2 Nos. 1-4).

As well as distribution at PM events worldwide, each issue of *Powder Metallurgy Review* will be mailed to selected PM industry professionals from our extensive *International Powder Metallurgy Directory* (IPMD) database. It will also be available to download, free-of-charge, in PDF format from the *ipmd.net* website. For those wishing to ensure that they receive every issue in print format, a subscription is available for £85 per year (approximately $135/€105) including airmail shipping worldwide.

We look forward to receiving your comments on the contents and direction of the new magazine, and to receiving any relevant news or editorial that you wish to submit for publication in future issues.

Paul Whittaker
Editor, *Powder Metallurgy Review*

Cover image
A 2012 MPIF award winning PM two-stage helical gear and spur pinion used in a power liftgate actuator, manufactured by Capstan Atlantic, Wrentham, Mass., USA (Photo courtesy MPIF)

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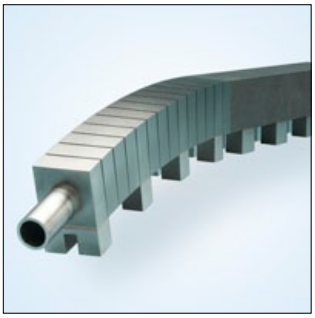

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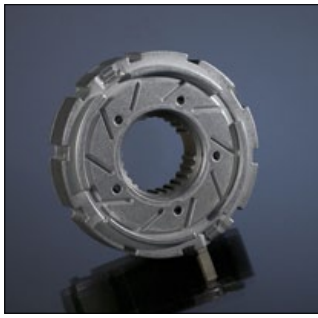

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To submit news for inclusion in *Powder Metallurgy Review* contact Paul Whittaker paul@inovar-communications.com

Höganäs reports stronger sales in Asia during Q2

Alrik Danielsson, CEO and President of Höganäs AB

Commenting on the second quarter results for Swedish powder producer Höganäs AB, CEO Alrik Danielsson stated, "In current market conditions, we are benefiting from our high exposure to markets outside Europe. The volume recovery in Asia, our largest market, continued after a 2011 negatively affected by the tsunami and flooding. As expected, Europe was noticeably weaker due to decreasing domestic demand, and there appear to be few prospects of any rapid improvement."

Second quarter 2012 net sales were MSEK 1,808, down 3% year on year. Demand conditions were better than in the corresponding period of the previous year in Asia and North America, but worse in Europe and South America. Operating income was MSEK 285 and income after tax was MSEK 202. Lower sales volumes and lower currency hedging earnings had a negative impact on income, while price increases and savings measures had a positive effect.

Höganäs sales by geographical region

First half year results (1 January - 30 June 2012) disclosed net sales of MSEK 3,621, down 0.5% year on year. Operating income for this period was MSEK 567 and income after tax was MSEK 405.

"Against the background of the concerns and uncertainty prevailing on the markets, we are pleased with sales nearly comparable to the previous year, adjusted for the exceptional deliveries to Hoeganaes Corporation (GKN) in 2011. Our operating margin and cash flow remain satisfactory, despite a visibly negative currency effect."

"We are retaining a fairly high rate of investment in research and development. Extensive work on the market launch of electromagnetic applications continues, and we made promising advances in the powder for Metal Injection Moulding (MIM) segment in the quarter," added Danielsson.

www.hoganas.com

Net sales MSEK	Second quarter		Accumulated	
	2012	2011	2012	2011
Europe	537	618	1,108	1,222
America	557	627	1,128	1,173
Asia	714	624	1,385	1,244
Total	**1,808**	**1,869**	**3,621**	**3,639**

Net sales for Höganäs by geographical region

Miba enjoys continued sales growth

Following its best ever year in 2011/2012 with full year consolidated sales increasing by 35.6% to €592.6 million, Miba AG of Vorchdorf, Austria, reported that sales in the first quarter of fiscal year 2012/2013 (February 1 to April 30) soared by a further 16% to €160.9 million compared with the same period last year.

"The success of the past business year continued to motivate us in the first quarter, and our volume of orders remains satisfactory," stated Peter Mitterbauer, Chairman of the Management Board of the Miba Group. Miba Sinter Group accounted for 35% of consolidated sales, followed by Miba Bearing Group at 32%. Miba Friction Group contributed approximately 23% to consolidated sales. Just under 8% comes from the New Technologies Group started last year.

www.miba.com

GKN reports increased profits for first half of 2012

GKN plc, the global engineering business that serves the automotive, aerospace and land systems markets, has reported increased profit and sales across the group. Sales were up 16% to £3,459 million in the first half of 2012, compared to £2,988 million in the same period of 2011. Operating profit for the group in the first six months of 2012 increased 31% to £293 million, compared to £224 million in 2011.

"GKN has continued to make good progress both in terms of financial performance and implementing our strategy to build a global market-leading business. First half trading has seen sales increases and margin progression for each of our four Divisions and our new acquisitions, Stromag and Getrag Driveline Products, are performing well," stated Nigel Stein, Chief Executive GKN plc.

"We expect 2012 to be another good year of progress for GKN and, in addition, we look forward to welcoming our new acquisition, Volvo Aero, into GKN when the transaction completes in the next few months," he added.

The GKN Powder Metallurgy division is one of the world's largest manufacturers of sintered components and comprises GKN Sinter Metals and Hoeganaes.

GKN Powder Metallurgy sales in the first half of 2012 were £465 million (2011: £435 million), an increase of 7%. The negative impact of currency translation was £10 million. Organic sales increased by £40 million (+9%). Hoeganaes increased the number of tons of powder shipped by 8%.

GKN Sinter Metals increased sales in all regions, benefiting from strong automotive production in North America and new business wins entering production. Organic sales for GKN Sinter Metals increased by 13% in North America and 3% in Europe. Strong growth was also achieved in India, Brazil and China.

Overall, GKN Powder Metallurgy reported a trading profit of £47 million (2011: £39 million). The negative impact of currency translation was £1 million. The divisional trading margin was 10.1% (2011: 9.0%). Return on average invested capital was 18.2% (2011: 15.7%), reflecting the improvement in profitability. At 31 December 2011, return on average invested capital was 16.7%.

Increasing trends in industrial and automotive markets to improve fuel efficiency and reduce emissions continue to drive the demand for products made by Powder Metallurgy, state GKN. During the period, around £80 million (annualised sales) of new programme business was awarded.

Additional $4m investment in Indiana site expansion

GKN Sinter Metals, LLC, plans to continue expansion of its Indiana site with a further investment of US$4m over the next year.

In a statement issued by the Indiana Economic Development Corporation (IEDC), GKN also plans to increase the workforce at the site to accommodate the increased production. In 2010, the company announced it would create a further 50 jobs at the site by 2013, but has already exceeded that goal by adding more than 75 new jobs (as of August 2012).

GKN committed in December 2010 to invest $3.45 million to equip its 220,000 square-foot facility in Salem. The company has since invested $7.1 million and plans to invest an additional $4 million in the next year. As part of the project, the company purchased compaction presses, sintering furnaces and automation for the furnaces and presses.

The Indiana Economic Development Corporation offered GKN Sinter Metals, LLC up to $250,000 in conditional tax credits and up to $100,000 in training grants based on the company's job creation plans. "With its optimal location, expansive infrastructure and high quality workforce, Indiana continues to hit the mark with automotive companies around the world," stated Indiana's Lt. Gov. Becky Skillman.

"Our plant has had a significant turnaround in the last four years, with our location in Salem as a tremendous asset in that process," stated Paul Cook, Director of Operations, Segment II at GKN Sinter Metals. "The result of our investment is a successful, sustainable business that is positioned well to continue to grow and prosper in Salem."

Expansion in China

GKN Sinter Metals states that it is expanding capacity to meet increasing demand from global and domestic customers in China. New equipment has been installed in its plant in Danyang, Jiangsu Province, which will increase production capacity by 30%.

The investment will see new presses, furnaces and induction hardening machines installed at the plant, all of which are said to be state-of-the-art equipment meeting GKN's global standards.

GKN Sinter Metals' business in China has been growing significantly and is expected to double in the next few years. The plant manufactures Powder Metallurgy components for automotive powertrain applications.

www.gkn.com

This differential bearing adjuster manufactured by GKN Sinter Metals won the MPIF's Grand Prize in 2011 (Photo courtesy MPIF)

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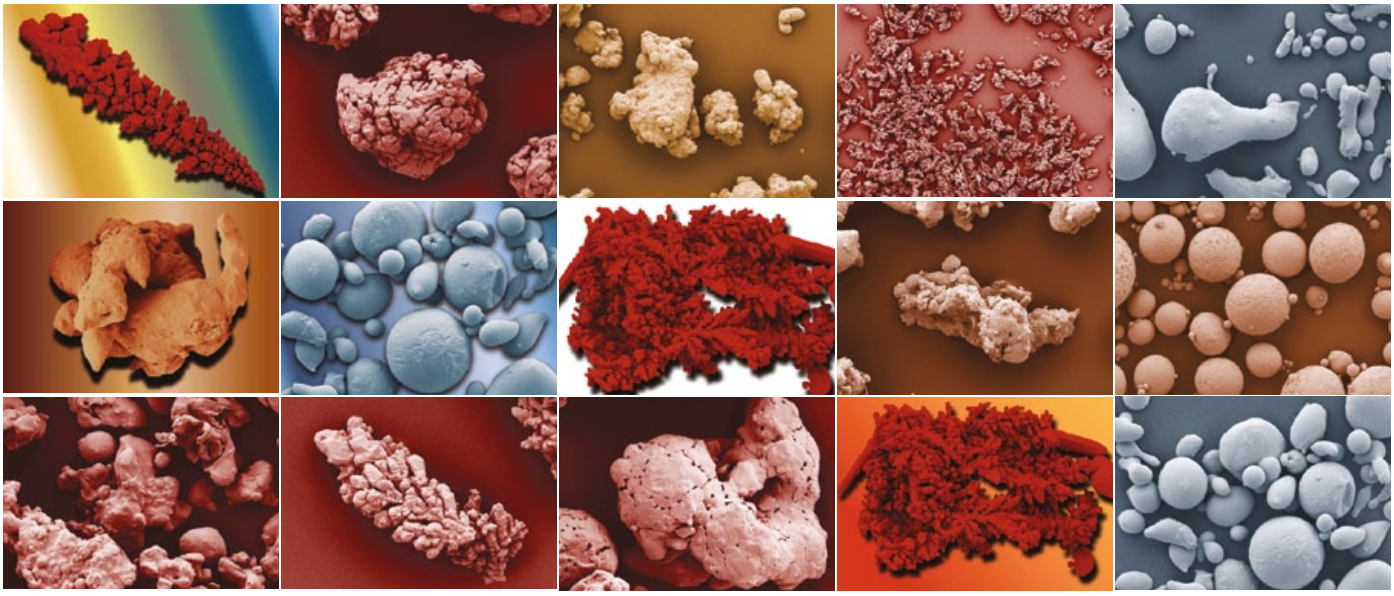

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Japan's PM industry reports good early growth in 2012

After the trauma which beset most of Japan's manufacturing industries due to the earthquake and tsunami in the north east of the country in March 2011, most industry sectors, including powder metallurgy, have been able to resolve problems and are back on track for growth in 2012.

The Japan Powder Metallurgy Association (JPMA) reports that iron powder shipments for PM increased to 46,499 tonnes in the first five months of the year, an increase of 13.5% compared with the same period in 2011, which was affected by the natural disaster from March 2011 onward. However, copper powder shipments for PM declined by 5.9% to 2,047 tonnes also in the same five month period.

The JPMA reported that production of structural PM parts reached 47,082 tonnes in the first five months of 2012 – an increase of 17.5% over the same period in 2011, and that production of PM bearings was up by 5% to 4,796 tonnes.

PM companies show mixed Q1 results

Japan's leading PM companies and conglomerates have, however, reported mixed results for the first quarter (April 1 to June 30) of the financial year 2012/2013.

A surge in global vehicle production has helped increase sales in a number of companies, but the earthquake and tsunami in North East Japan in March 2011, and also the severe flooding in Thailand later that year, continues to impact others.

Sumitomo Electric Group

Japan's Sumitomo Electric Group has seen a significant rebound from the devastating effect of the Great East Japan Earthquake that effected sales in the 2011/2012 financial year (April 2011 to end March 31, 2012). The group has reported a 19.4% increase in sales to Yen 527.2 billion ($6.699 billion) for the 1st quarter of the current financial year (April 1 to June 30, 2012).

Growth was achieved on the back of a global rise in vehicle production

PM components used in a high response VVT system produced by Sumitomo Electric Group (JPMA 2011 award winning part, image courtesy JPMA)

and demand for the Group's automotive related products, which make up more than 50% of sales. Net income increased more than threefold to Yen 13.9 billion ($176 million) for this period.

The 'Industrial Materials & Others' division is one of six business segments at Sumitomo Electric and includes the production of cemented carbides (hardmetals), PM parts, and the fully owned A.L.M.T. subsidiary that produces W, Mo, heavy metal, thermal management materials, ceramics, diamond tools and hardmetals.

The division, which makes up around 13% of group sales, reported 1st quarter sales up by 5.3% to Yen 69.1 billion ($877.8 million) with PM part sales flat at Yen 10.9 billion ($138.4 million) compared with the same period in 2011/2012. Hardmetal sales showed an increase of 6.9% to Yen 18.5 billion ($235 million), and A.L.M.T. sales were slightly down in the 1st quarter at Yen 9.7 billion ($123 million).

global-sei.com

Mitsubishi Materials Corp. (MMC)

Despite the gradual recovery from the Great East Japan Earthquake and the robust recovery in demand for automobile related products, the drop in copper prices and stagnant demand for semiconductor related markets has seen Mitsubishi Materials Corp. (MMC) 1st quarter net sales (April-June 2012) down by 12.4% to Yen 309,674 billion ($3.934 billion) compared with the corresponding period last year. Net income for the 1st quarter decreased by 1.9% to Yen 5,398 billion.

MMC's 'Advanced Materials & Tools' division, which includes the production of cemented carbide tools and structural PM parts, reported a 1% increase in sales in the 1st quarter to Yen 36.6 billion ($465 million) but a 27% drop in operating profit to Yen 3.2 billion ($4.066 million).

Cemented carbide tools sales were negatively impacted in 2012 by the flood damage at the company's MMC Carbide Tools facility in Thailand, which is undergoing repairs.

Capital expenditure by the Advanced Materials & Tools division in 2012 jumped to Yen 11.4 billion, an increase of 98.7% over the amount spent the previous year.

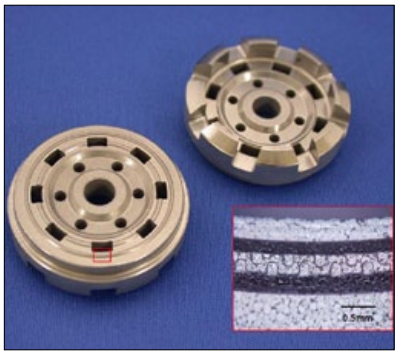
www.mmc.co.jp

Hitachi Chemicals Ltd.

Hitachi Chemicals Ltd reported a small (0.2%) decrease in 1st quarter 2012/2013 group sales to Yen 117,981 billion ($1.499 billion) but a much sharper decline (27%) in profits, which fell to Yen 6,782 billion ($86.176 million). The company states that this reflects the substantial damage caused by the Great East Japan Earthquake and tsunami and the repairs needed at production facilities.

The 'Advanced Components and Systems' segment of Hitachi Chemicals includes Automotive Products (structural PM and MIM parts, PM bearings, friction materials, and plastic moulded products), Energy Storage Devices and Systems (vehicle batteries, capacitors) and Electronic Components (printed wiring boards).

Hitachi Chemicals produce this light-weight sinter diffusion bonded carrier used in a 4WD transmission (JPMA 2011 award winning part, image courtesy JPMA)



A sintered base valve seat used in shock absorbers for automobiles from Fine Sinter (JPMA 2011 award winning part, image courtesy JPMA)

This segment achieved 1st quarter sales of Yen 55,209 billion ($701.5 million), an increase of 7.3% over the same period in 2011/2012.

Sales of PM products were up thanks to the recovery in car production, and sales of friction materials also recovered following the transfer of production to new sites due to the closure of the original friction materials operation located close to the Fukushima Dai-ichi Nuclear Power Plant.

Hitachi Chemicals states that first half sales to September 30, 2012 and fiscal year end March 31, 2013, are expected to exceed the forecasts previously announced. The company is forecasting half year sales of Yen 245,000 billion ($3.1 billion) by the end of September 2013.

www.hitachi-chem.co.jp

Fine Sinter Co., Ltd.

Fine Sinter Co., Ltd., one of Japan's leading PM producers, reported that year-on-year sales to March 31, 2012, shrank by around 3% to Yen 33.65 billion ($424 million) but with net income increasing by 67% to Yen 2.138 billion ($27.2 million).

For the 1st quarter (to end June 2012) the company stated that it had achieved sales of Yen 9,097 billion ($115.5 million) with net income of Yen 473 million. Sales have continued their upward trend over the past four quarters following the disruption caused by the earthquake and tsunami in March 2011.

www.fine-sinter.com

Nippon Piston Ring Co., Ltd.

Nippon Piston Ring Co., Ltd., Japan's leading producer of automotive engine parts such as piston rings, cylinder liners, and valve train parts, including structural PM parts and complex parts made by Metal Injection Moulding, reported full year results for 2011/2012 ,which saw sales rise by 3.7% to Yen 49,168 billion ($624.9 million) in a turbulent market.

Sales in the 1st quarter of the current financial year (2012/2013), however, remained flat compared with the previous quarter at Yen 12,584 billion ($159.8 million).

www.npr.co.jp

Ceratizit invests in Günther Wirth

The Ceratizit Group has announced that it plans to acquire a 50% share of German tool manufacturer Günther Wirth (GW).

Günther Wirth specialises in the production of rotary cutting tools from hardmetal. The Wirth Group was founded in 1981, and besides the parent plant in Swabian Balzheim, Germany, includes production sites in France, India, the USA and Italy. The family owned company employs around 500 people and is one of the leading manufacturers of rotating cutting tools such as drills, end mills, reamers and rods.

"With this acquisition, we will be able to cover the whole value chain in hardmetal production - from powder, to tool blanks to custom-made and coated round tools such as drills and end mills," stated Jacques Lanners, representative of the Ceratizit Executive Board. In the future, GW will be incorporated into the Ceratizit Group as a global business unit, and will remain as a brand.

"The GW brand is superbly positioned in the case of end users and dealers - in Europe and in the USA and India. As a part of the Ceratizit Group we want to develop this offering worldwide", stated company founder Günther Wirth. Ceratizit and GW have worked closely together for many years and have already cooperated in the manufacture of blanks and finished tools.

The transaction is expected to be completed, subject to the finalisation of due diligence and approval by the anti-trust authorities, by the end of 2012. Ceratizit and the current shareholders around the company's founder Wirth will each hold 50% of the GW company after the transaction is finalised. Both private companies have agreed not to disclose any financial details.

Jacques Lanners (left) representative of the Ceratizit Executive Board and GW founder Mr Günther Wirth (right)

www.ceratizit.com
www.gw-tools.de

Hitachi Chemical expands its PM production in China

The Chinese subsidiary of Hitachi Chemical Co., Ltd., Hitachi Powdered Metals (Dongguan) Co., Ltd. (HPMD), is to expand production capacity through construction of a new factory at its existing site in Guangdong.

The Chinese auto market is expected to grow by 10% per annum, states the company, and the new facility is in direct response to the increased demand from this market. Production is planned to commence at the new factory in autumn 2012.

HPMD manufactures Powder Metallurgy products for the Hitachi Chemical Group and has technical expertise in the automobile and construction machinery sectors. In addition to products currently manufactured at the site, the production of sintered bearings, which are seeing increasing demand in China, is to commence.

Hitachi Chemical Group has powder metal product manufacturing locations in Japan, China, the US, Singapore, Thailand, Indonesia and India (to commence operation in April 2013).

www.hitachi-chem.co.jp

H.C. Starck and Jiangxi Rare Earth & Rare Metals Tungsten Group Holding expand tungsten business in China

H.C. Starck and Jiangxi Rare Metals Tungsten Group Holding Co. Ltd. (JXTC), one of China's largest tungsten mine operators, have celebrated the ground breaking ceremony for their tungsten joint venture in Ganzhou City, Jiangxi Province, China. Scheduled to start operations in late 2013, the new plant will produce tungsten metal powders and carbides exclusively for the Chinese market.

"This joint venture is our largest project to date in China and the core of our growth strategy in Asia. I am pleased that we could win an experienced and reliable partner like JXTC for this project," stated Andreas Meier, President and CEO of the H.C. Starck Group. "We will primarily supply the products of our joint venture to the hard metal manufacturers for the automotive and engineering industries as well as to suppliers for the mining and energy industry in China," he added. "Demand for higher quality tungsten products continues to increase in China. With our joint venture, we will be able to serve this market over the long term."

"This cooperation plays to the competitive strengths of both partners and creates a new model of close cooperation between Chinese and German high-tech companies," stated Zhong Xiaoyun, President and CEO of JXTC.

The previous preparatory work for the joint venture has been strongly supported by government authorities. "We are convinced that the joint venture will contribute to resource preserving and sustainable development of the Chinese tungsten industry and, as a result, will be a business success for all parties involved," explained both Zhong and Meier. "The joint venture will also strengthen H.C. Starck's raw material supply chain. And the facility will create about 400 new jobs which will boost the economic and social development of Jiangxi Province."

Ganzhou is one of the largest cities in the province of Jiangxi, which has large natural-tungsten deposits. Advanced tungsten products are used as high performance materials in a variety of growth industries, including speciality cutting tool manufacturing, wear parts for mining, tunnel and read construction, as an alloy metal, and for components in the aerospace and medical engineering industry.

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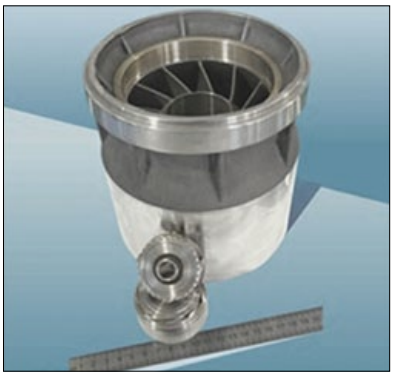
Forming your ideas

Novomet utilises PM and Laser Sintering for submersible centrifugal pump parts

Novomet, based in Perm, Russia, claims to be the country's largest producer of electric submersible pumps (ESPs) used in harsh oil and gas well conditions including high gas to oil ratios, heavy oils, high temperatures, and in abrasive and corrosive fluids.

The company, which was established in 1991 and currently employs around 4,000 people worldwide, uses patented technology to produce complex shaped PM stainless steel components for the demanding applications in ESPs. The stainless steel powder grades are used to produce the pressed and sintered stage pump parts with complex shapes and internal cavities for submersible centrifugal pumps used in oil production.

The pumps have been specially developed for operation in reservoir fluids such as hydrochloric acid and hydrogen sulphide and are therefore required to have high corrosion resistance.



Electric submersible pump produced by Novomet as part of downhole ESP system

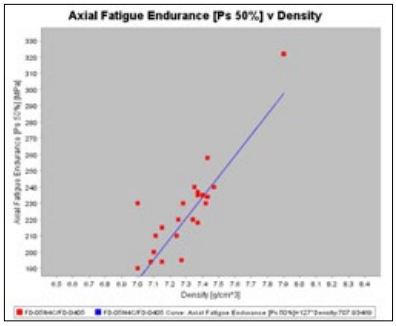
In addition the PM stainless steel grades are required to have high abrasion resistance in the harsh operating conditions. The company also produces PM abrasion resistant radial and axial bearings for its centrifugal pumps. The bearings are made from a tungsten carbide base material, which is said to have improved plastic characteristics and resistance to vibration and impact loads.

Novomet has installed a SLS (Selective Laser Sintering) system for the production of 3-D prototype parts from powdered materials for evaluation in ESPs and other applications.

www.novomet.ru

New upgrade for Global Powder Metallurgy Property Database

The ground-breaking online Global Powder Metallurgy Property Database (GPMD) was launched in 2004 as a joint project between the world's three leading regional PM trade associations, the European Powder Metallurgy Association (EPMA), North America's Metal Powder Industries Federation (MPIF) and the Japan Powder Metallurgy Association (JPMA).



An example of the data that can be extracted from the Global PM Database

Since its launch, the database has been refined and extended to include the non-ferrous PM and MIM sectors with coverage of nearly 4000 lines of high quality data.

In the latest development, additional information covering recently introduced hybrid ferrous structural grades, based on the sinter-hardening material, FL-5108, and the diffusion-alloyed material, FD-0105 has been added.

The data is displayed in a user-friendly interface viewable in both tabular and graphic formats and it is hoped it will be of particular interest to design engineers in a range of industries.

www.pmdatabase.com

Pittman Motors uses range of PM components in new planetary gearbox

Pittman Motors, part of the AMETEK Precision Motion Control division, has introduced a new compact planetary gearbox as an addition to their extensive line of DC motor and gearmotor products.

The G30A planetary gearbox incorporates sintered steel planet gears to promote high torque capacity and low audible noise while maintaining a compact design.

Single piece carrier plates with integral gear posts and sun gear can be arranged to achieve many different reduction ratios.

The gearbox output is through a 416 stainless steel shaft and a sintered metal output bearing.

The G30A gearbox is a perfect complement to the Pittman brush and brushless DC motors, states the company. When the G30A is combined with the latest motor materials and manufacturing technology such as high energy neodymium magnets, silicon lamination steel, and advanced winding techniques to maximise slot fill, a high efficiency system is created perfectly suited for high-tech motion applications.

Pittman also offers a wide variety of complementary products such as gearboxes, encoders, brakes, and drive systems.

www.pittman-motors.com

Fine Sinter to establish new PM plant in Indonesia

Fine Sinter Co. Ltd., one of Japan's leading PM producers, has reported that it is establishing a new manufacturing subsidiary in Indonesia.

The new PM plant will start operations in January 2013 with an expected workforce of around 110 people.

Currently the company has five manufacturing subsidiaries in Japan, Thailand, North America and China.

www.fine-sinter.com

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ITER nuclear fusion heat exchanger set for series production using Plansee expertise

It's possible to generate power in an environmentally compatible and sustainable way using nuclear fusion. This, states Plansee SE, based in Reutte, Austria, is what the international research project ITER (International Thermonuclear Experimental Reactor) has set out to prove by 2030 at the latest.

Only components that meet the most stringent technical requirements can be considered for use in the ITER system. Above all, the heat exchangers of the diverter are subject to extreme temperatures.

Plansee states that is has recently reached the final qualification phase prior to series manufacture with its components and is now looking to become established as one of the key suppliers to ITER.

International cooperation

Seven nations are currently working together on building a nuclear fusion plant as part of ITER, the world's most extensive fusion experiment. For the first time, the plant is intended to deliver more power than is required for generating and maintaining the plasma. Some of the requirements on the components stretch the limits of what can be achieved with today's technology.

Test scale components from Plansee have already proved themselves and have made a significant contribution to the reference design of the forthcoming ITER plant. Plansee was recently awarded the contract for manufacturing full-scale prototypes. This final stage before series manufacturing is a serious challenge, and only three companies worldwide were able to qualify.

How does nuclear fusion work?

Energy is released when hydrogen nuclei fuse to form helium nuclei. That is the simple recipe for success behind this environmentally friendly and sustainable source of energy. The shining example of this process is the sun, which also generates energy using the same principle. But although it may sound simple, it is in fact the result of the complex interplay of many factors.

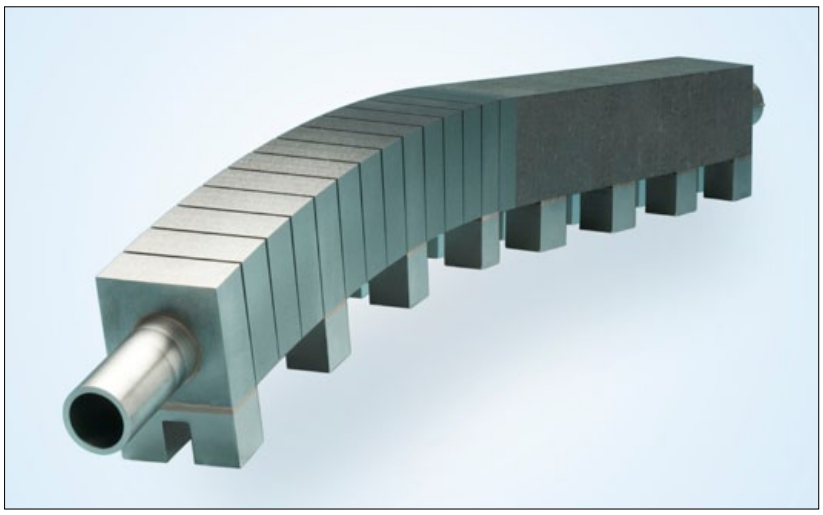
In the nuclear fusion plant, hydrogen gas will be heated to temperatures in excess of 100 million °C. This produces a plasma in which the electrons are separated from the nuclei. At these extreme temperatures, hydrogen nuclei possess sufficient kinetic energy to collide with each other despite the repulsive electric force between them, and fuse to form helium nuclei. Recoverable energy is released during this nuclear fusion process.

A magnetic field encloses the hot plasma in order to maintain the fusion process and to protect the components of the plant as much as possible. Only very few components come into contact with the outer regions of the plasma. One area that becomes particularly hot is the divertor.

At particular points in the magnetic field, generally near the bottom of the plasma vessel, the helium ions and impurities in the plasma are guided towards the divertor. There, the ions are slowed down and electrically neutralised. In order to prevent the divertor components from melting or even vapourising, the heat that has been generated must be removed as quickly as possible.

If the divertor is unable to withstand the extreme stress, the continuous operation of the fusion plant is simply not possible. As a result, only composites that can withstand an extremely high level of generated heat of up to 20 MW/m² and are capable of resisting the ceaseless attack of electrons, ions and impurities are used in the divertor.

In principle, the divertor is made up of a highly efficient heat sink for dissipating the heat protected by an armour. The armour protects the heat sink from being damaged by the hot plasma during operating conditions.



The current reference design for the high-performance heat exchangers for the ITER divertor involves monoblocks manufactured from tungsten and carbon fibre reinforced graphite (CFC) that are joined to a CuCrZr alloy tube using a patented joining technology. The channel sections on the bottom are manufactured from special steel and are intended to be used later for connecting the assembly to the support structure of the ITER divertor. The figure shows a prototype having approximately 25% of the final overall length

Material choice

Tungsten and carbon are the materials of choice for this armour. These materials are particularly heat resistant and dissipate heat very efficiently. Unlike carbon, tungsten does not bind a large amount of hydrogen and has a low interaction with the plasma resulting in lower impurity levels of the plasma. This makes tungsten a particularly suitable material in highly loaded areas of the first wall of nuclear fusion plants.

As a leading expert for refractory metals, Plansee manufactures armour composites for the divertor made from carbon fibre reinforced carbon (CFC) and tungsten monoblocks and joins the armour to the copper/chromium/zirconium-based heat sinks. Plansee states that its particular expertise lies

not only in the resilient materials themselves, but also in the joining technology used within the composite.

Once the fusion plant has been taken into operation, any repairs represent a huge outlay in terms of time and money. Any downtime of the plant, no matter how short, is an expensive exercise. Only a perfect joint between the armour and the heat sink prevents overheating and damage to the divertor. Plansee has developed and patented its own joining process specifically for the nuclear fusion industry: "active metal casting". This method ensures that heat is transmitted to the heat sink extremely efficiently and reliably.

Over the course of the coming months, the team from Plansee will be working together with a large number of engineers and production staff to construct the first full-scale partial segments of the divertor for ITER. All the individual steps in production must be perfectly coordinated and technically harmonised.

Joining some 130 armour blocks to the backing tubes of the heat sink in a single step without the slightest error is just one of the many challenges to be overcome during the project. Traditional quality assurance measures are not appropriate to the complexity of this development task. In order to be absolutely certain, Plansee has developed its own non-destructive testing methods for ITER based on thermographic and ultrasound techniques.

Stress testing on all ITER prototypes should be completed successfully by mid 2014. Series production of the ITER components can then start.

www.plansee.com

Record profits for Sandvik in first half of 2012

Operating profits for Sandvik AB in the first half of 2012 amounted to 8,031 million SEK (6,834 million SEK in 2011), the highest level recorded to date.

The operating margin was 15.8% (15.0) of invoiced sales in the period January - June 2012. Changed exchange rates had a positive impact of 250 million SEK on earnings during the first half of the year, compared with a year earlier, while changed metal prices had a negative impact of 118 million SEK.

Order intake increased to 55,084 million SEK (50,262) up 10% in total and 7% in fixed exchange rates for comparable units. Invoiced sales were 50,776 million SEK (45,451), up 12% in total and 9% in fixed exchange rates for comparable units.

Sandvik stated that the global market demand improved during the first half of the year compared with the first six months of 2011, although uncertainty increased towards the end of the period.

The improvement was most tangible for Sandvik Mining and North America in general.

www.sandvik.com

For the latest news from the PM industry, register for our free e-newsletter at www.ipmd.net/enews

Höganäs turns to HIP technology for high performance PM gears for rally cars

In 2011 Swedish iron powder producer Höganäs AB and SwePart Transmission replaced the 4th set of gears in Ramona Karlsson's rally car with Powder Metallurgy gears. After proving that Powder Metallurgy gears could match the performance of the original steel gears, the next step was to replace the remaining gears to create a complete PM transmission solution.

Ramona Rally team races in a Mitsubishi EVO X during the 2012 season

In 2012 the Ramona Rally team races in a new car, a Mitsubishi EVO X, with a new transmission housing manufactured by Australian company Pfitzner Performance Gearboxes (PPG) and containing PM gears that have been manufactured using Hot Isostatic Pressing (HIP).

During a recent rally competition in Karlskrona, Sweden, the Ramona Rally team had another opportunity to test drive the sintered gears, and once again reported good results.

"It went very well and we got further proof that the sintered gears work really well. As this was a rather challenging racing track, it was a perfect opportunity for us to verify the performance ahead of the WRC competition in New Zealand in June," stated Ramona.

Since a rally car's gear box typically is replaced two to three times during a World Rally Championship (WRC) season, Höganäs has now developed five complete gear boxes together with SwePart Transmission.

On August 24-26, 2012, the German town of Trier hosted a WRC competition. For this race Höganäs arranged a special event including the opportunity to experience live rally and to watch Ramona and PM gears in action.

No HIP with Hipaloy®

Ramona has also been involved in the testing of gears manufactured from Höganäs' Hipaloy® material. By analysing reports on gear shifting under full throttle, the intention has been to investigate how a PM gear that had not been HIPed performs in racing conditions in comparison to a steel gear.

This EVO X contains PM gears that have been manufactured using HIP

A Mitsubishi EVO8 with performance similar to a typical rally car has been used for the test and the goal is to run 1,000 km. Up until now the car has been driven for more than 600 km with good results and no gear damages have been found after inspection.

To watch Ramona and her co-driver Miriam in action, visit the official website: www.ramonarallying.com

Höganäs also reported that the Smartcar with its gearbox containing PM gears had reached 100,000 km with no problems.

www.hoganas.com

Hagen Symposium to focus on PM raw materials and future application trends

The Hagen Symposium on Powder Metallurgy, organised by the Ausschuss für Pulvermetallurgie, is a key annual event in the German-speaking countries of Europe and brings together more than 250 delegates from industry, research, and academia over a two day period to review trends in PM technology and its products.

The 31st Hagen Symposium will take place as usual at the Town Hall in Hagen, November 29-30, 2012, and in addition to a full technical programme will feature more than 50 exhibitors.

The Skaupy Prize for 2012 will be presented to Dr Lorenz Sigl, Director of Research at Plansee SE, Reutte, Austria.

The organisers state that the key objective of the 2012 Symposium will be to review trends in a wide range of PM industry sectors, including ferrous and non-ferrous powder developments.

In addition to the Skaupy presentation by Dr Sigl, which will focus on innovations in PM technology for the energy sector, there will be presentations on the use of ceramic membranes in 'Carbon Capture and Storage (CCS) in coal fired power plants (M. Schröder, Inst. For Physical Chemistry, TU Aachen), and the production of PM metal and metal-ceramic composites for power plant membranes (H.-P. Buchkremer, Forschungszentrum Jülich).

The 31st Hagen Symposium will conclude with hard material related presentations covering new developments in coatings for cutting tools, new concepts for diamond tools, and the impact of availability of tungsten raw material on the hard metal sector.

www.pulvermetallurgie.com

ESPG launches new projects

The European Structural Parts Group (ESPG) is one of the sectoral working groups of the European Powder Metallurgy Association (EPMA).
The ESPG recently launched a new club project on 'Component Fatigue Strength (Phase 1) in partnership with RTWH IPAK Aachen, which has the objective to predict the fatigue strength at constant stress ratio R of a PM component by a material master curve for three ferrous PM alloys.

The viability of the method will be demonstrated using a PM injector clamp for common rail systems produced by AMES, which is supporting the project financially along with GKN Sinter Metals, MIBA, and PMG Füssen.

The EPMA reports that final results and Roadmap for possible next stages for this project should be made available in October 2012.

www.epma.com

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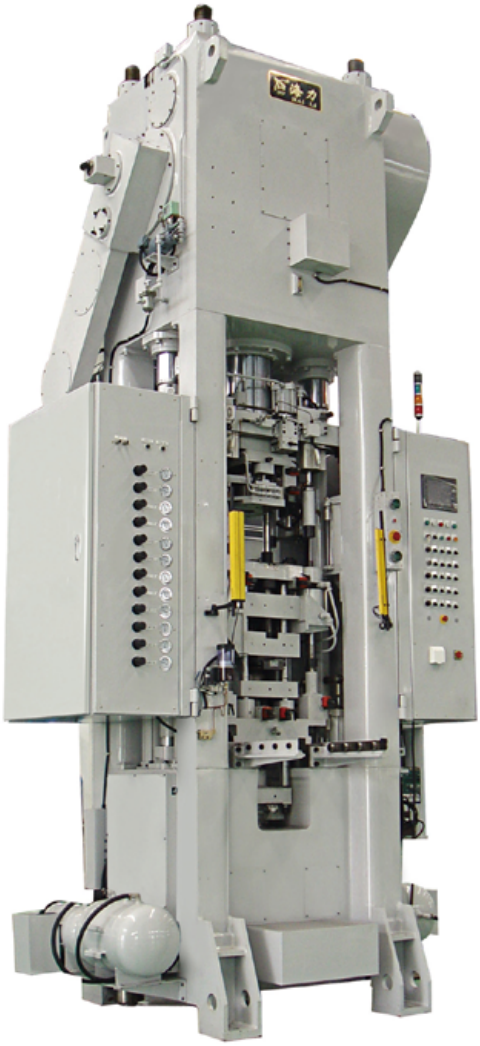

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Toshiba develops dysprosium-free samarium-cobalt magnet to replace heat-resistant neodymium magnet in essential applications

Toshiba Corporation has announced the development of a high-iron concentration samarium-cobalt magnet that is free of dysprosium, a rare earth mineral that is in extremely short supply and increasingly expensive.

At typical operating temperatures, the samarium-cobalt magnet has superior magnetic properties to the heat-resistant neodymium magnets currently used in motors.

The traction motors for hybrid and electric automobiles, railroad vehicles and the motors for industrial equipment operate at relatively high temperatures, and heat-resistant neodymium magnets are generally used in these applications. Dysprosium is a key material of these magnets, but current sources of dysprosium are limited.

Recent export limitations and price rises are raising global concerns for future shortages and the development of dysprosium-free high performance magnets that offer a strong magnetic force at high operating temperatures is an important objective for industry.

Toshiba states that it has used heat-treatment technology to improve the magnetic force of the samarium-cobalt magnet, and in doing so has boosted its performance to a level surpassing that of the heat-resistant neodymium magnet. The high-iron concentration samarium-cobalt magnet exceeds the heat-resistant neodymium magnet in magnetic force by 1% at an operating temperature of 100°C and by 5% at 150°C.

Toshiba achieved this by reducing the oxide and the phase with high copper concentrations in the magnet, both of which inhibit magnetic force, and by increasing the amount of iron in the magnet from 15% to 20% by weight.

Toshiba has verified the performance of the new magnet when applied in motors for automobiles, locomotives, machine tools and elevators, confirming that it has almost the same capabilities as heat-resistant neodymium magnets of the same size. The magnet is highly suited to motors that must combine high heat resistance with high performance and a small size.

The company aims to start mass production of the magnet at the end of the current fiscal year and promote its use in all applicable equipment.

Development of the magnet and motor was supported by Japan's New Energy and Industrial Technology Development Organisation's (NEDO) Rare Metal Substitute Materials Development Project.

www.toshiba.co.jp

Metal prices soften on declining demand

Some of the key metals used in the production of Powder Metallurgy products such as structural parts, self-lubricating bearings, and hardmetal tools, have seen marked downward slides over the first half of 2012 mainly as a result of declining demand and the resulting oversupply and build up of stocks.

For example, tungsten production in China increased by a reported 16% to 57,585 tons in the first half of 2012, but with the global market largely expected to stay weak there is potentially an oversupply situation. Chinese tungsten APT export prices have declined from just under $410/mtu at the start of 2012 to a range between $370 and $375 in mid-August. WC powder (3-4 microns) FOB P.R.C. fell below $45/lb in August from around $55/lb at the beginning of the year.

LME copper, which has dropped more than 27% from a record $10,190/ton in February 2011, has been stuck in a narrow trading range between $7,300 and $7,600/t since July 2012. Nickel has also moved downwards from $11/lb in August 2011 to less than $7/lb in August 2012.

Plansee Group reports sales of more than Euro 1.5 billion

The Plansee Group has announced sales of more than €1.5 billion in the last fiscal year. "Despite the global uncertainties caused by government debts, Euro and banking crisis we were able to successfully continue our worldwide expansion during 2011," Plansee Group's Executive Chairman, Dr. Michael Schwarzkopf, stated at the annual press conference in Reutte.

Consolidated Group sales increased by 22% in the last fiscal year (ended February 29, 2012) to reach €1.52 billion. According to Schwarzkopf, "Business developed satisfactorily in all divisions and in all important regions for Plansee. Increased sales volumes and raw material prices, acquisitions and changes within the group portfolio had a significant impact on sales growth."

At the regional level, the Plansee Group benefited from the robust US economy and Germany's export strength. Strong growth was also achieved in China and India. Sales outside of Europe slightly increased to 52% of the Group total (America 32%, Asia 20% and Europe 48%). More than half of Group sales were achieved in three market sectors mechanical engineering, automotive and consumer electronics.

Focus on high-technology materials molybdenum and tungsten

With the acquisition of a 10% share in the Chilean company Molibdenos y Metales (Molymet) in March of last year and the sale of the sintered parts manufacturer PMG at the end of 2011, the Plansee Group is now focused on the two key-materials molybdenum and tungsten. "We will continue expanding our global market position in this business field," explained Schwarzkopf.

Due to the sale of PMG, which employed 1,150 people worldwide, the Group's workforce was down from 6,730 to 6,120 employees at year-end.

A new plant of the Plansee High Performance Materials division is scheduled to come on stream in Shanghai in late 2012.

www.plansee.com

New 648 page PM directory includes essential technology reviews

The 15th Edition of the International Powder Metallurgy Directory, 2012-2013, was published by Inovar Communications Ltd earlier this year. This 648 page publication contains essential PM market and technology information, as well as a comprehensive directory of companies active in the PM industry worldwide.

Powder Metallurgy's leading reference source for 35 years

The *International Powder Metallurgy Directory* (IPMD) is an essential reference publication for anyone involved in the global PM industry. The directory not only contains details of nearly 4800 companies involved in PM, but also includes more than 190 pages of PM market and technology information.

The 15th Edition IPMD is the most comprehensive guide ever published to both PM component producers and industry suppliers worldwide.

What does the directory cover?

The IPMD directory lists not only Powder Metallurgy industry suppliers, but also all known Powder Metallurgy parts and product producers. Some 200 product codes are used to identify each company's specific area of activity.

The IPMD is an indispensable tool for those involved in PM, for end-users and industry analysts. Listed below are the main product categories included in the IPMD:

PM PRODUCTS

- Sintered structural parts
- MIM / CIM
- Special PM alloys
- Magnetic/electrical parts
- Cemented carbides
- Diamond tools
- Heavy metals
- Friction materials
- Bearings
- Sintered filters
- Foam structures

PRODUCTION EQUIPMENT

- Powder production
- Mixing and milling
- Powder presses
- Compacting tools
- Sintering furnaces
- Atmospheres/generators
- Finishing
- Processes/coatings
- Automation
- Testing and analysis

METAL & ALLOY POWDERS

- Iron and steel (including stainless)
- Non-ferrous
- Refractory metals
- Carbide and ceramic
- Magnetic
- Ultrafine/nanocrystalline
- Hardfacing
- Pressing lubricants

Trade associations, research centres, universities and consultants are also included.

On-line database access included

All purchasers receive 12 months access to the on-line IPMD database, searchable via the www.ipmd.net website.

The 648 page 15th Edition International Powder Metallurgy Directory, 2012-2013

Purchase information

The *International Powder Metallurgy Directory* 15th Edition is published by Inovar Communications Ltd. ISBN 978-0-9558223-2-2. The publication is A4, soft cover, 648 pages. Price: £195 including airmail shipping worldwide. www.ipmd.net

Detailed PM market and technology information

In addition to the fully revised and updated "*Powder Metallurgy: A Global Market Review*" (see facing page), the IPMD contains essential information on all aspects of PM technology and applications. Features in the 15th Edition IPMD include:

PM PARTS & PRODUCTS

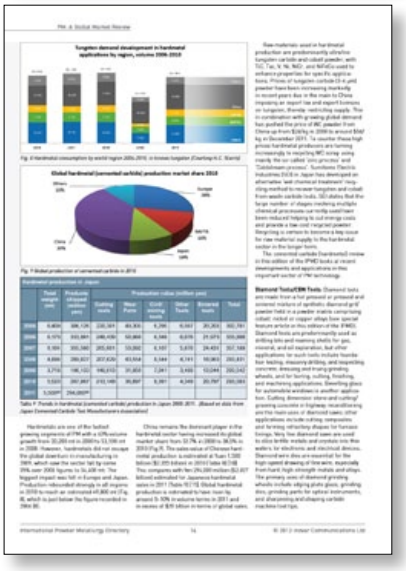
- Developments in the Production of Structural PM Components
- High Density, High Performance Powder Metallurgy Components
- International Award Winning Parts
- Metal Injection Moulding (MIM): Materials, Processes and Applications
- Complex shaped metal powder components made by Additive Manufacturing
- Innovations in Tungsten Carbide-Cobalt Hardmetal Technology
- Production and Applications of PM Diamond Tools
- PM Superalloys for High Temperature, High Performance Applications
- PM Fully Dense High Alloy Steels
- An Introduction to Powder Metallurgy Soft Magnets
- Powder Metallurgy Permanent Magnets and their Applications
- PM Self-Lubricating Bearings Continue to Make Advances

PM MATERIALS & PROCESSING

- Trends and Innovations in Powder Compaction Presses and Die Sets
- Sintering Equipment and Atmospheres used in Powder Metallurgy
- Trends in Ferrous Powders for use in Powder Metallurgy
- Non-Ferrous Powder Production Technologies
- Trends in Nano Powder Production and Applications

Market report highlights the resurgence of the global PM industry

"Powder Metallurgy: A Global Market Review" presents a detailed analysis of the current status of the global Powder Metallurgy (PM) industry. Included in the 15th Edition International Powder Metallurgy Directory, or available to purchase as a separate PDF download, the review provides essential market data on the global PM industry.



Powder Metallurgy: A Global Market Review, presents a detailed analysis of the current status of the global Powder Metallurgy (PM) industry. The report's author, Bernard Williams, formerly Executive Director of the European Powder Metallurgy Association, presents extensive data on how the PM industry has witnessed a resurgence in fortunes since the financial crisis of 2008.

Published by Inovar Communications Ltd, the report also presents data on the emergence of China and other Asian countries as the leading global region for the manufacture of powder metallurgy products.

The review covers all aspects of PM production, including structural components, high alloy PM steels, copper and copper-base products, hardmetals/cemented carbides, diamond tools, refractory metals, and powder-based magnets. Powder metallurgy's special relationship with the automotive industry is also addressed.

"The global PM industry regained its growth momentum in 2010 and 2011 after the turbulence caused by the financial crisis of 2008 and the ensuing economic recession. Ferrous PM part production was set to break through the one million tonnes barrier in 2011 and the prospects for 2012 remain very positive," stated Williams.

"The Powder Metallurgy industry is on a positive footing not only because of volume growth in existing applications, but thanks to continuing technological innovations that are helping to push the boundaries of how and where PM can be used. From new high performance automotive gears to complex components for hybrid vehicles and fuel cells, the technology is proving to be invaluable for the development of the next generation of green vehicles."

Powder Metallurgy – A Global Market Review, also features an inset review of the current status of Metal Injection Moulding (MIM) and Ceramic Injection Moulding (CIM). Collectively known as Powder Injection Moulding (PIM), this technology has enjoyed dramatic growth over recent decades and is estimated to have reached record global sales of $1.2 billion in 2011.

"The PIM industry has shown itself to be capable of significant annual growth, which has averaged 13% per annum over the past 10 years," commented Williams. "This high growth rate is expected to continue in the years ahead with some forecasts predicting Asia to double sales from 2009 levels by 2014. North America is forecast to achieve sales of around $425 million in the same timeframe. Europe is expected to have the lowest annual regional growth rate but still at a healthy 11.6%. This will take global MIM sales close to the $2 billion mark by 2015."

"The global PM industry regained its growth momentum in 2010 and 2011 after the turbulence caused by the financial crisis of 2008. Ferrous PM part production was set to break through the one million tonnes barrier in 2011 and the prospects for 2012 remain very positive"

The 12,500 word market review, which includes some 25 tables and 35 figures, costs £145 and is available to download in PDF format from www.ipmd.net/marketreview. The review is also available in print as part of the new 15th Edition *International Powder Metallurgy Directory* 2012-2013.

About Inovar Communications Ltd

Inovar Communications Ltd, based in the UK, is a specialist technical publishing company dedicated to the Powder Metallurgy (PM) and Powder Injection Moulding (PIM) industries. As well publishing *Powder Metallurgy Review*, the company's portfolio of publications includes *Powder Injection Moulding International, ipmd.net* - the premier on-line resource for the PM industry, the weekly *ipmd.net e-newsletter* and the *International Powder Metallurgy Directory*.

www.ipmd.net.

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Recent trends in Hot Isostatic Pressing (HIP): Processing and applications

The processing of primarily large Powder Metallurgy (PM) near-net shapes such as superalloys, tool steels, stainless steels, and titanium by Hot Isostatic Pressing (HIP) has been used extensively since 1970 and an estimated 1000 HIP systems* have been installed since that time. HIP systems are also used for defect healing of castings, diffusion bonding and cladding, and fully densifying hardmetals (cemented carbides). Bernard Williams looks at trends in HIP process technology and applications for powder materials.

Hot Isostatic Pressing (HIP) involves the simultaneous application of high pressure (15,000 to 45,000 psi) and elevated temperature (up to 2500°C) in a specially constructed vessel. The pressure is usually applied with an inert gas such as argon, and so is 'isostatic'. Under these conditions of heat and pressure internal pores or defects within a solid metal body collapse and diffusion bonding occurs at the interfaces. Encapsulated powder and sintered components can also be fully densified to give improved mechanical properties and a reduction in the scatter band of properties. In some cases, such as large powder metallurgy semi-products or large near-net shape PM components weighing several tonnes, HIPing is the only viable manufacturing option.

In a recent presentation Susan Davies, General Manager of Bodycote HIP Ltd in the UK [1], stated that HIP conditions are generally chosen so that the gas pressure at a specific temperature exceeds the yield stress of the material at that temperature. Under these conditions plastic flow occurs on a microscopic scale allowing the formation of isolated pores, which then collapse to allow direct contact of the two surfaces. This in turn allows bonding across the interface due to the diffusion of atoms in both directions.

The closure of internal porosity in castings by HIP without affecting the microstructure has considerable benefits in improving the reliability of a casting, particularly when the castings are used in the aerospace, medical, automotive, offshore and marine sectors, stated Dr Davies.

HIP systems

A HIP system requires a pressure vessel, inert fluid (gas), means of pressurising the fluid (gas), and a heating system. The original hot isostatic press used a monolithic forged steel autoclave sealed by a threaded top closure through which the inert gas, argon, was pumped. The requirements

Fig. 1 A large hot isostatic press with a working diameter of 1.62m and height of 2.33m (Courtesy Avure Technologies)

*Around 50% of these HIP installations were for R&D applications.

Fig. 2 Hot isostatic presses with hot zone diameter up to 1650 mm are built by EPSI Inc.

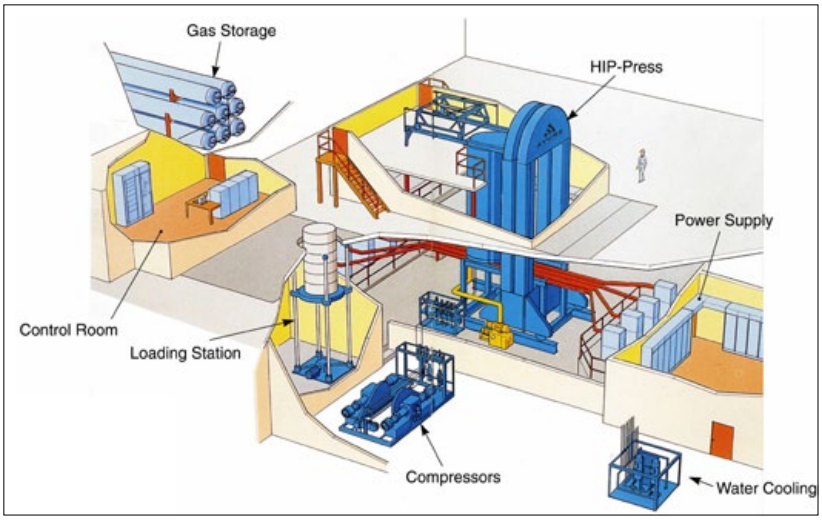

Fig. 4 Layout of the world's largest HIP system installed at Metals Technology Ltd in Japan to densify large castings and to produce PM parts for the aerospace, electronics and petroleum industries. The HIP system was produced by Avure Technologies, Sweden

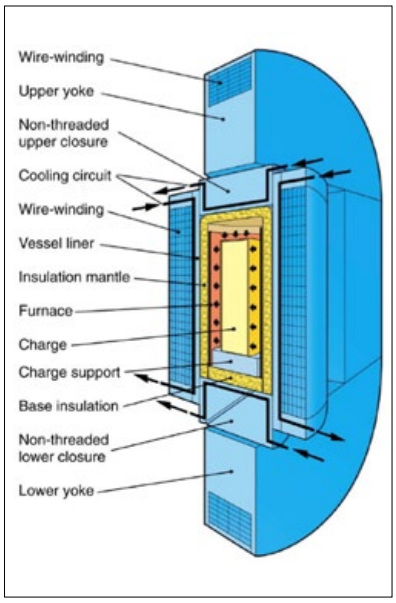

Fig. 3 The pressure vessel is the backbone of any HIP system. (From presentation by A. Eklund, Avure Technologies, at 'Workshop on HIP Processing of Materials for Aggressive Environments', Derby, UK, November 16, 2011)

for ever higher pressures and/or temperatures has seen the development of new designs of HIP systems including multi-wall forged, relatively thin-walled vessels surrounded by tight fitting forged steel rings, or steel wire wound. Two examples of commercial HIP equipment are shown in Fig. 1 and Fig. 2.

In the steel wire wound system, for example, the radial forces are taken up by a forged steel cylinder pre-stressed with kilometers of high strength steel wire (Fig. 3). The axial forces are transferred through the two moving closures to the external frame, which is also pre-stressed with the wire winding. Pressure is sealed within the vessel using Bridgman seals, metal-to-metal seals, single or double O-rings, or a combination of these. The pre-stressing causes the pressure vessel wall to remain in residual compression even at maximum operating temperature, eliminating tensile loads, and preventing crack propagation and brittle failure. Such a vessel has a calculated fatigue life of more than 20,000 cycles [2].

Fig. 4 shows the layout of the world's largest 'giga-HIP' system built by Avure Technologies (Sweden) and installed at Metals Technology Ltd in Japan in February 2010. The system has a 2050 mm inside working diameter by 4200 mm tall, which can process parts at temperatures up to 1350°C and pressures of 1180 bar (17,000 psi). Avure Technologies believes that the next generation of HIP equipment will have working diameters of at least three meters and over five meters in height, and there are preliminary designs that would allow a 4000 mm working hot zone diameter.

The availability of such large HIP systems and the associated advances in cycle time reduction due to rapid cooling, has made the use of HIP as a powder consolidation process considerably cheaper in general terms than it was 20 years ago. An example of HIP process cost reduction is given in Fig. 5 [3]. The data in the figure assumes a HIP pressure of 1050 bar, and includes labour costs, utility and maintenance costs, and a five shift operation for 300 days/year.

> *"the next generation of HIP equipment will have working diameters of at least 3 meters and over 5 meters in height"*

The heart of the HIP system

Avure Technologies believes that if the isostatic pressure vessel is the backbone of a HIP system, then the furnace is the heart (Fig. 6). The furnace consists of resistance heater elements arranged in multiple, independently controlled zones. The choice of furnace and heater element materials will depend on the material being HIPed and the temperature. For temperatures up to 1350°C Fe-Cr-Al alloys (Kanthal) can be used as heater elements. Molybdenum can be used in the temperature range 500 – 1600°C, and graphite for temperatures from 400 to 2200°C or higher. Graphite has the advantage of lower cost than refractory metals and has good strength and dimensional stability at high temperatures.

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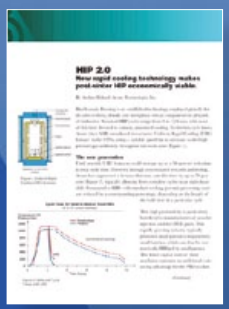

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HIP ø 1.8 m x 3.3 m	HIP ø 1.8 m x 3.3 m
14 h cycle time	8 h cycle time
4 hour hold time	4 hour hold time
20 tons/cycle	2 tons/cycle
10000 tons per year	1800 tons per year
0.3 EUR/kg	0.9 EUR/kg

Fig. 5 Examples of HIP cost reduction using large HIP systems [3]

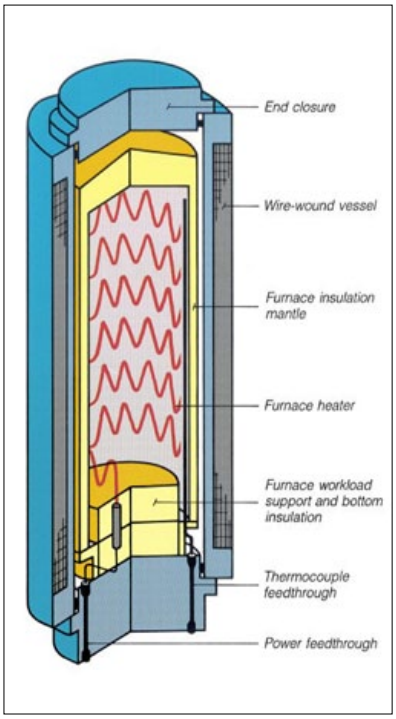

Fig. 6 Schematic of a modular plug-in wire wound HIP vessel produced by Avure Technologies with multiple heating zones and patented insulation mantle design [2]

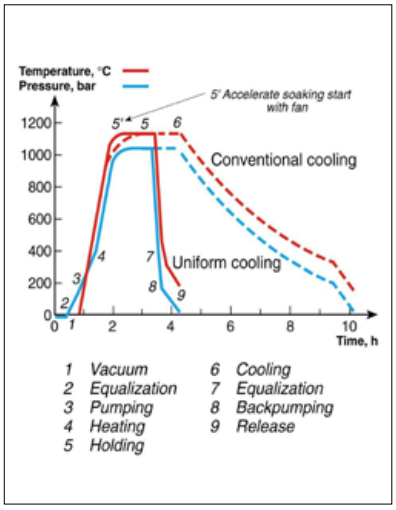

Fig. 7 HIP cycle for a large Quintus® system with and without URC [2] (Courtesy Avure Technologies)

Graphite furnaces are used primarily for the HIPing of ceramic materials but also for HIPing of cemented carbides (WC-Co materials).

Properly operated and maintained the furnace will perform flawlessly for more than 10 years of continuous, demanding service.

Avure's Uniform Rapid Cooling (URC) technology and quench furnaces are equipped with a forced convection system which circulates cooler gas through the work zone. Cooling rates of 100°C/min (above 800°C) and a heating rate of 30°C/min for a D=1.2 meter hot zone with a 2000 kg load can be achieved without affecting the size of the hot zone significantly.

For smaller HIP vessels this temperature change rate, including the load, can be 300°C or even 400°C, depending on the vessel size [4]. This provides decreased cycle time, improved productivity, and can even combine HIP and heat treating. Fig. 7 shows a typical HIP cycle for an Avure Quintus® system with and without URC.

Containers for powders

Whilst solid metals such as castings or sintered parts can be loaded directly into the HIP furnace, blended metal or alloy powders are first filled into high quality steel containers which must be strong enough to maintain shape and dimensional control but be soft and malleable at the HIPing temperature. An example of a container filled with Alloy 625 powder is shown in Fig. 8 [5].

The standard container is between 2 and 3 mm thick. Containers are normally degassed at intermediate temperatures (ca. 300°C), sealed, preheated and then HIPed in a pressure vessel. In the case of PM superalloys, typical HIP conditions are a temperature of between 1100 and 1260°C and a pressure of 100 to 200 MPa, which is maintained for several hours with argon as the pressurising medium. The superalloy powders are consolidated to full density during HIPing by pressure assisted sintering. The container is removed by rough machining and/or pickling to reveal the near net-shape component. Compound products can also be produced by designing capsules with separate compartments for different powders or enclosing parts of solid material together with the powder.

Recent developments in computer modelling of the HIP process by the French consortium of SNECMA, Turbomeca, and Tecphy (now Aubert & Duval) and also VILS in Russia, have led to the production of complex near-net HIP shapes to very high dimensional precision with critical surfaces held to within 0.25 mm.

"Recent developments in computer modelling of the HIP process have led to the production of complex near-net HIP shapes to very high dimensional precision"

Powder based HIP products

The HIP systems described above have often been designed for specific applications such as converting powder into fully dense products (metal, carbide and ceramics) by pressure assisted sintering, post-HIP of sintered products to eliminate porosity, and the production of bimetallic products.

The HIP temperatures can range from 1100°C for powder consolidation of PM tool steels, to 1500°C for the elimination of porosity in hardmetals (cemented carbides), and exceed 2000°C for HIPing of ceramics.

Pressures of up to 200 MPa can be achieved. The length of the HIP cycle can take several hours so there are economic advantages in having as big a workload in the press as possible.

The development of 'mega' (1.6 m diameter) and 'giga' HIP (2.05 m diameter) systems in recent years has come alongside the significant increase in powder production capacity, particularly high grade spherical shape powder particles suitable for HIP produced by gas atomisation.

This has resulted in a wide choice of alloy powders such as stainless steels, tool steels and high speed steels, as well as nickel-based and cobalt-based super alloys which are now being produced in large quantities

in a variety of particle sizes at competitive prices.

The conversion of gas atomised powders into 100% dense products having near-net shape components often weighing several tonnes, with a refined microstructure and mechanical properties superior to cast or wrought equivalents, has made hot isostatic pressing an essential PM processing route for a growing number of application areas.

PM high alloy steels

The use of HIP to produce PM tool steels was developed simultaneously, but independently, in Sweden by Stora Kopparberg and ASEA (now Erasteel) and by Crucible Materials Corp in the USA (Crucible Particle Metallurgy Process – CPM) in the 1970's.

The use of gas atomised tool steel powders and HIP led to the elimination of segregation found in cast materials, and the very fine distribution of primary carbides in the HIPed microstructure resulted in superior mechanical properties such as compressive strength, hot hardness, and toughness.

The high wear resistance of PM tool steels helped to secure increasing market share in the intervening decades and they are now extensively used in metal forming tools and other applications.

PM high speed steels are also produced by the HIPing of gas atomised powders, and one example is the HIPed gear cutting hob shown in Fig. 9. These PM HSS materials are said to bridge the gap between conventional high-speed steels and cemented carbides.

The early landscape of PM high alloy steel producers has changed significantly over the past decade. ASP® grades are now produced by Erasteel, a member of the ERAMET Group.

When Sandvik Powdermet, based in Surahammar, Sweden, acquired Metso Powdermet AB from the Finnish Metso Oy Group in 2006, it acquired a leading producer of near-net-shape HIPed PM components ranging in weight from 100 g to 15 t covering high alloyed steels, stainless steels, Ni and Co base alloys and metal matrix composites (MMC).

This has given the company a foothold in the offshore components market, utilising its near net shape expertise to produce complicated high alloy PM HIPed components, including for subsea development projects. Areas of importance are HIPed components for multi-fluid analysis, wye-pieces for pipeline installations, manifolds for topside and subsea installations, valve bodies for choke and control valves, and swivels for FPSOs.

Manifolds are, for example, used for collecting oil/gas from well heads as well as for water injection. They are subjected to sour service and high pressure, and therefore require high mechanical strength and corrosion resistance (Fig. 10). The Duplex stainless FPSO Swivel component has internal passages for oil/gas, water injection and power connection.

Although Metso Materials Technology no longer produces HIPed components in-house, the company's Engineered Materials & Components Division in Lokomo, Finland, continues to develop and use HIP technology for a growing range of applications.

One example given by the company [6] is a superaustenitic 254 SMO stainless steel ball valve used in a desulphurisation plant in oil refineries. The HIPed components are required to operate in a highly corrosive hydrogen sulphide environment containing oil/gas. The as-HIPed valve half is shown on the left in Fig. 11 after the removal of the HIP capsule and Fig. 11 right shows the as-machined part. The HIP route produced a material with superior properties and allowed easy and reliable ultrasonic inspection.

Undoubtedly one of the most impressive Metso applications for PM high alloy steels are the stainless steel end covers for the CERN particle accelerator located in a 27 km long ring-shaped tunnel 100 m underground near Geneva. The choice of end

"The use of gas atomised tool steel powders and HIP led to the elimination of segregation found in cast materials"

Fig. 8 (top) Pre-HIP filled can weighing 2050 kg with 1525 max OD; (middle) post-HIP 1345 mm maxOD; (bottom) heat treated and sonic machined HIPed part [5] (Courtesy Carpenter Technologies)

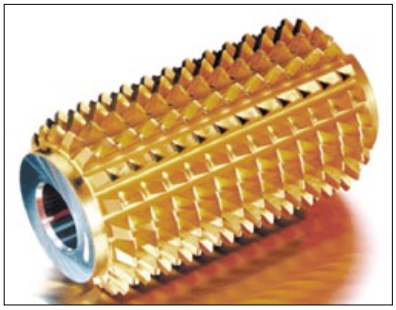

Fig. 9 HIPed gear cutting hob from MICOPCLEAN high alloy high speed steel powder. (Courtesy Böhler-Uddeholm Powder Technology)

Fig. 10 Offshore manifold system in Super Duplex stainless material. Total weight of the manifold is 26 tonnes. (Courtesy Sandvik Powdermet)

Fig. 11 (left) As-HIPed body part for ball valve with capsule removed and heat treated. (right) HIPed body part as-machined [6]

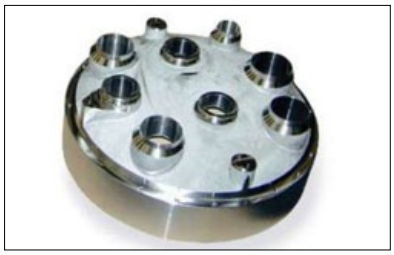

Fig. 12 HIPed stainless steel 316LN end covers for CERN particle accelerator. [6]

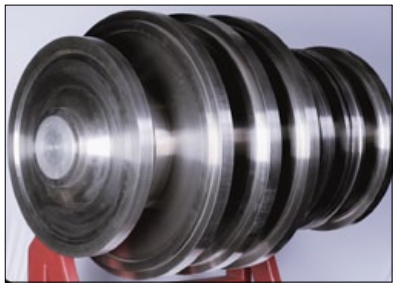

Fig. 13 As-HIPed PM superalloy parts for turbine discs and compressor discs having diameter 150 – 950 mm and weighing up to 300 kg (Courtesy VILS Joint Stock Co)

Fig. 14 As-HIPed turbine casing made from SYP3 PM superalloy by Aubert & Duval for the SNECMA CFM 56-5 aero engine [8]

Fig. 15 Chromium (PM) sputter targets/ billets (Courtesy Bodycote HIP Ltd) [9]

cover material was a fully dense HIP stainless steel 316LN grade of which Metso supplied some 2700 pieces, (Fig. 12). Metso has also supplied around 20 tonnes of HIPed PM stainless steel 316LN radial plates for the ITER fusion reactor project.

Bodycote in Surahammar, Sweden, has since 2010 also been operating a very large HIP unit and Erasteel doubled its powder production capacity in Söderfors, also in Sweden, opening a new large capacity gas atomiser in 2011.

PM superalloys

Improvements in gas atomisation technology to produce finer, cleaner, high purity nickel-base powders has seen PM superalloy near net shape (NNS) components produced by HIP find increasing applications in the aero and land based gas turbines as well as other sectors such as energy.

Static and dynamic mechanical properties of HIPed superalloy products can be at the level of, or very close to, extruded + forged products [7]. HIP parameters and final heat treatment conditions can be readily adapted to control the grain size and precipitate distribution in the microstructure of the PM superalloys.

This has led to the development of specific PM superalloy grades with higher alloying content than conventional cast and wrought grades, which allow aero engines to withstand higher combustion temperatures and pressure ratios resulting in increased fuel efficiency and performance. It would be difficult, if not impossible, to produce similar superalloy compositions by the cast and wrought routes.

The HIP route also allows the production of bi-metal parts with dual properties. One example is a turbine disk with high yield strength at the intermediate temperatures in the hub and with high creep resistance at the rim [7].

A further significant development has been the computer modelling of the HIP process, which has led to the production of NNS PM superalloy components. A French consortium of SNECMA, Turbomeca and Tecphy (now Aubert & Duval) and separately VILS in Russia have successfully developed modelling technology to produce complex shaped as-HIPed components. As-HIPed PM superalloy turbine discs produced by VILS are shown in Fig. 13. An as-HIPed turbine casing made from SYP3 (Astroloy-type grade PM superalloy) for the SNECMA CFM 56-5 aero engine is shown in Fig. 14.

Sputtering targets

Another significant application for hot isostatic pressing is the production of sputtering targets used for coatings, magnetic memory materials and microelectronic layers. High purity, homogenous materials with 100% density can be produced from chromium, refractory metals, ceramics or other materials which cannot be made by melting technology.

HIPed sputtering targets may be further HIP diffusion bonded to a suitable supporting substrate or backing plate. Bodycote HIP, a leading producer of HIPed components and provider of HIP services, has developed capsule technology which the company states opens up a range of sizes, designs and chemical composition of sputtering targets. Fig. 15 shows some HIPed chromium powder billets.

Promoting HIP technology

Although the first in a series of successful international conferences on isostatic pressing was organised by the author and his team at MPR Publishing in the UK as early as 1978, and a specific 'International HIP Conference' series was started in Lulea, Sweden in 1987, the awareness of PM HIP technology and its potential was still considered to be limited compared with some other PM technologies.

In 2009 the MPIF established a separate 'Isostatic Pressing Association (IPA)' in North America to provide more information and education on the area, and in 2010 the EPMA established a European counterpart in the form of the European PM HIP

Group (EPHG). Adeline Riou (Erasteel, France), chair of the EPHG, stated that collective actions by the trade associations can be an effective way to improve the awareness of HIP. The group has published a free educational brochure on HIP that can be downloaded as a PDF.

The EPHG will be organising a Special Interest Seminar on 'Materials Properties & Materials Selection for Hot Isostatic Pressing' (Wednesday, September 19 2012) to coincide with the EuroPM2012 Conference and Exhibition scheduled for Basel, Switzerland, September 16-19 (www.epma.com/pm2012).

A technical session devoted to HIP took place at the PowderMet 2012 Conference & Exhibition, Nashville, USA, June 10-13 (www.mpif.org), and will also feature at the PM2012 Powder Metallurgy World Congress & Exhibition, Yokohama, Japan, October 14-18, (www.pm2012.jp).

Further information on the activities of the isostatic pressing groups can be obtained from the two trade associations: www.mpif.org and www.epma.com.

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North America's Powder Metallurgy industry maintains its growth momentum

In comments delivered during the opening session of PowderMet 2012, the International Conference on Powder Metallurgy & Particulate Materials, Nashville, USA, June 10-13, Matthew Bulger, President of the Metal Powder Industries Federation, stated that in all materials, process and market sectors, the North American Powder Metallurgy (PM) industry has built on the growth momentum that began last year.

"Traditional press-and-sinter PM, Metal Injection Moulding (MIM), Hot Isostatic Pressing (HIP), and other specialty PM technologies are thriving," stated Bulger. "PM is an interconnected technology that innovates and grows by leveraging its different sectors."

Looking back at the past two years, it was suggested that the industry's recovery is sustainable. Iron powder shipments soared in 2010 after a difficult previous year. Total North American iron-powder shipments grew modestly in 2011 to 363,831 short tons, a 3% increase that was achieved despite the shutdown of a major powder supplier's main plant for two months.

Shipments of copper and copper-based and tin powders gained almost 19% in 2011 to 17,002 short tons. Stainless steel powder shipments increased about 5% to an estimated 7,000 short tons.

Shipments of North American MIM grade powders, including imports, jumped nearly 40% in 2011 and the MIM process, it was suggested, continued to garner greater acceptance in the materials marketplace. Some interesting R&D programmes were highlighted, included MIM ultrasonic dental scaler tips and endodontic tips, as well as titanium and cobalt–chromium alloys for medical implant applications.

The HIP business has also experienced robust growth in 2011 due to a general surge in manufacturing and gains in the oil-and-gas, tool-steel and aerospace markets. The HIPing of MIM parts, noted Bulger, continues to be a growing market.

Sustained growth ahead

Bulger stated that 2012 began on a very positive note, with rising confidence levels. First-quarter shipments of metal powders are up, as are volumes of PM parts and MIM parts.

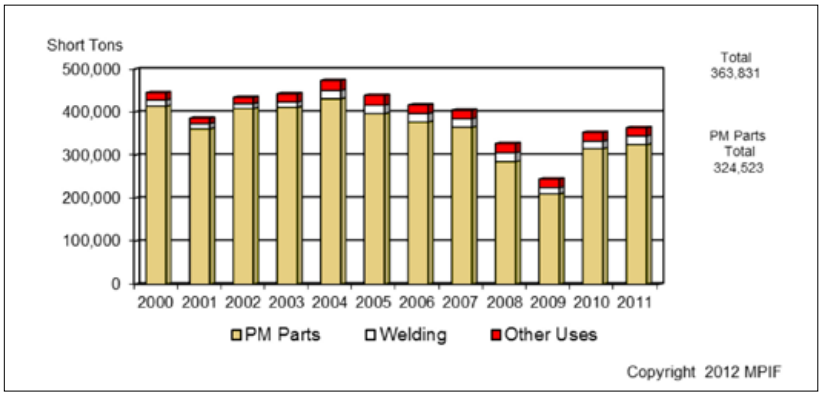

Fig. 1 North American iron powder shipments (Courtesy MPIF)

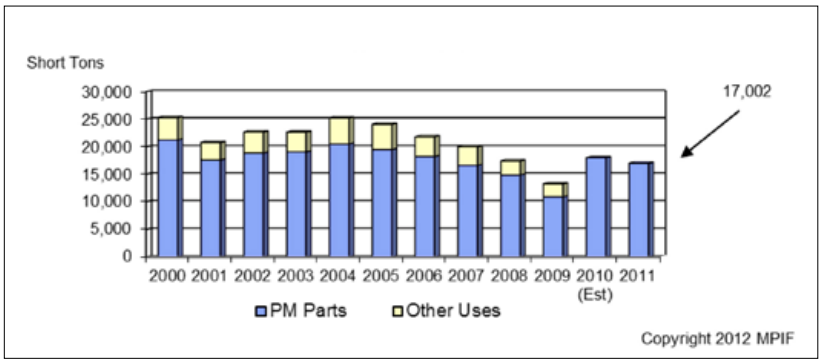

Fig. 2 North American shipments of copper, copper-based and tin powders (Courtesy MPIF)

Fig. 3 Matthew Bulger, President of the MPIF, welcomes delegates to PowderMet 2012

U.S. light-vehicle sales are expected to top 14 million units, up substantially from the 12.8 million units sold in 2011.

Iron-powder shipments through April this year rose by 11.25% to 134,925 short tons. Copper and copper-base and tin powder shipments have remained stable.

Capacity constraints

"One of the key issues facing the entire industry is the serious need for experienced production workers and PM engineering professionals. Industry-wide employee reductions during 2008–09 have not been easy to reverse as the industry has rebounded."

Another issue highlighted was capacity constraints, "Will the industry be ready to meet rising demands, particularly driven by the automotive industry, in the next several years?" asked Bulger.

As was the case with staffing, rationalisation moves during the same 2008–09 period included several plant closings and the scrapping of older equipment. "Because it can take upwards of 10 to 12 months to build a high-end metal powder press and put it into production, the equipment investment bandwagon must begin rolling sooner rather than later."

The automotive sector

Within the automotive sector, PM is approaching a saturation point in auto-engine content with existing technology. The average auto engine now contains up to 50 PM parts weighing more than 18 pounds, including connecting rods, bearing caps, valve-seat inserts, and VVT parts.

With the average North America–built engine containing up to 170 individual parts, PM parts currently represent about 30% of the content. Potential growth appears more likely, it was stated, in transfer-case and transmission applications.

Educating automotive engineers about PM's benefits has always been an important aim of the MPIF Industry Development Board (IDB). This year, stated Bulger, the IDB launched a new Automotive Showcase programme to bring PM's design-benefit-value message to PM's single largest market.

"The average auto engine now contains up to 50 PM parts weighing more than 18 pounds"

PM technology developments

The machinability of PM materials

New additives that improve the machinability of PM materials were highlighted as a significant advancement. "As mechanical-property demands rise, so does the need to improve the machining performance of sinter hardened and heat-treated materials." Researchers, it was stated, are also developing new lubricants for high-density applications.

Lightweight materials

The growing demand for lightweight materials is encouraging new attention aimed at PM aluminium, titanium, and magnesium structural applications. Boeing, it was stated, has recently qualified PM titanium alloy products for commercial aircraft use as an alternative to machining parts from bar, plate, castings, forgings, or extruded products.

Copper-powder products also offer new opportunities for growth. Applications that take advantage of copper's conductivity properties, as well biomedical applications offer significant opportunities.

High performance PM equipment

PM equipment suppliers, commented Bulger, are striving to advance the technology with new products such as larger tonnage CNC hydraulic compacting presses, more-stringent tolerance capabilities in the micron range, upgrading controls on older compacting presses, and high-performance sintering furnaces.

PM Industry Roadmap

Bulger reported that an updated PM Industry Roadmap, a project of MPIF's Technical Board, Industry Development Board, and numerous additional industry experts, has been recently released. Based on the first Roadmap completed in 2001, the update shows that the industry has made steady progress in high-density processing, new materials, 3-D forming systems, modelling, and advanced manufacturing methods.

Looking ahead, the new Roadmap identifies three main topics that will impact the industry's growth: high-density PM components, processing of lightweight materials, and electrical and electromagnetic applications. While the current PM industry is driven by automotive applications, growth in the next decade must be found in other markets. The overall need for alternative energy sources should open new markets and applications for PM.

In closing, Bulger noted that the PM industry is truly unique for its close-knit band of large and small companies who are devoted to promoting the entire industry and encouraging its growth. By being truly interconnected globally, the industry will continue to succeed and thrive in the years ahead.

www.mpif.org

Award winning parts demonstrate Powder Metallurgy's many advantages for critical applications

Winning parts in the Metal Powder Industry Federation's (MPIF) 2012 Powder Metallurgy Design Excellence Awards competition were announced at the PowderMet 2012 International Conference on Powder Metallurgy and Particulate Materials, Nashville, USA, June 10-13. In this article we present all the award wining components.

The following award winning parts exemplify PM's special engineering benefits, namely net shape, precision, innovative fabrication methods, production efficiency, energy and materials savings, and manufacturing cost reduction.

These advantages, states the MPIF, continue to stir designers to choose PM for critical applications in auto engines and transmissions, electronics, medical devices, agricultural equipment, consumer products, military, and emergency applications. In an increasing number of design decisions, PM jumps to the front of the line ahead of traditional forging, die casting, stamping, investment casting, and machining processes.

Grand Prize Awards

Automotive: Engine

GKN Sinter Metals, Auburn Hills, Michigan, USA, won the grand prize in the automotive engine category for a VVT rotor adapter assembly consisting of a PM steel rotor and adapter (Fig. 1). The parts are joined by an adhesive, which joins them during machining of cross holes and other features on the inside diameter, and seals the joint between them.

The assembly, used in a Chrysler V-6 engine, is mounted to the engine camshaft. Formed to a density of 6.8 g/cm^3, the rotor has an ultimate tensile strength of 60,000 psi, yield strength of 55,000 psi, and a 23,000 psi fatigue limit. The adapter is formed to a density of 6.9 g/cm^3, and has a minimum ultimate tensile strength of 58,000 psi, and yield strength of 53,000 psi.

After sizing and grinding, there is no other machining performed on the rotor. The adapter is not machined prior to assembly and is made to net shape with vertical slots for oil feeding. However, the customer machines the cross holes for the oil feed.

Automotive: Transmission

GKN Sinter Metals also won the grand prize in the automotive transmission category for a unitized one-way clutch (OWC) module (Fig. 2)) made for the Chrysler Group LLC, Auburn Hills, Michigan.

The module has four PM steel parts (powder-forged race and cam, and two pressed-and-sintered retainer plates) as well as 22 additional parts (clips, springs and roller elements). This product is the first self-contained loose-roller OWC module for torque converter stator applications using all PM and powder-forged main components.

The retainer plate has net-shape features that cannot be formed by other manufacturing processes without major secondary operations. Selecting the PM process reduced production costs by 20% and increased the volume rate by 50%. PM's reliability is supported by more than 10 million OWC assemblies in the field with zero warranty claims.

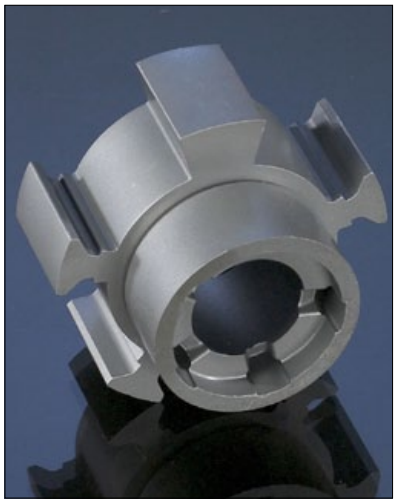

Fig. 1 PM steel rotor and adapter used in a VVT rotor adapter assembly

Fig. 2 Unitized one-way clutch module used in automotive transmissions

Fig. 3 PM two-stage helical gear and spur pinion used in a power liftgate actuator

Fig. 5 Copper-infiltrated PM steel inside deadbolt chassis

Fig. 4 PM steel gear race used in the OnTrac2 GPS-assisted steering system

Fig. 6 Stainless steel rotor used in a hand-emplaced munition device

Automotive: Chassis

The grand prize in the automotive chassis category was awarded to Capstan Atlantic, Wrentham, Mass., USA, for a complex PM steel two-stage helical gear and spur pinion used in a power liftgate actuator (Fig. 3).

Made to a nominal density of 6.85 g/cm^3, the combined helical gear–and-pinion design features precision journals for precise orientation in the actuator assembly. The part has a tensile strength of 65,000 psi and a yield strength of 55,000 psi.

The precise elemental gear data tolerances enable quiet gear performance, decreasing noise, vibration, and harshness.

Lawn & Garden/Off-Highway

FMS Corporation, Minneapolis, Minnesota, USA, won the grand prize in the lawn & garden/off-highway category for a PM steel gear race (Fig. 4) used in the OnTrac2 GPS-assisted steering system made for Novariant Corporation, Fremont, California, USA.

The system positions agricultural planting and harvesting equipment to more accurately perform tillage, spraying, and spreading as well as reducing skips and overlaps, thus reducing fuel consumption. Moulded to a density of 6.7 g/cm^3, the part has an ultimate tensile strength of 60,000 psi, minimum yield strength of 50,000 psi, 125,000 psi transverse rupture strength, and 23,000 psi fatigue limit.

The complex net-shape design features 112 gear teeth and 16 assembly holes. In addition to a 60% cost savings over the previous machining method of making the part, the PM design reduced the assembly part count from 24 to six parts. Selecting PM also cut lead times and allowed for easier assembly and disassembly in the field.

Hardware/Appliances

A copper-infiltrated PM steel inside deadbolt chassis (Fig. 5) made by ASCO Sintering Co., Commerce, California, USA, for a new commercial electronic lock system won a grand prize in the hardware/appliances category.

Made to a density of 7.4 g/cm^3, the part has an ultimate tensile strength of 110,000 psi, 75,000 psi yield strength, and 100 ft/lbf unnoticed Charpy impact strength. Maintaining the density between the hub and flange is especially critical. The part has two PM posts manufactured and installed while maintaining true position and squareness.

Secondary operations include adding the tapped posts, two slots on the shelf flange, two counterbores, and a countersink. PM was selected over castings and stampings, which could not meet strength or Builders Hardware Manufacturers Association requirements for integrity during high-temperature tests.

Aerospace/Military

FloMet LLC, Deland, Florida, USA, won the grand prize in the aerospace/military category for a very complex 17-4 PH stainless steel rotor (Fig. 6) made by metal injection moulding (MIM) and used in a hand-emplaced munition device.

The intricate design is demonstrated by its four holes on two perpendicular planes, two angled slots with square corners, and numerous internal and external radii, flats, slots, and cutouts. All of these features require very tight tolerances: 0.0025 inches to 0.005 inches. Moreover, the square bottom-hole could only be formed by MIM because prior attempts with other fabrication processes, including machining, proved unsuccessful.

It is estimated that the machined version of the part could cost as much as five times that of the MIM design. The rotor is made to a density of 7.5 g/cm^3 and has an ultimate tensile strength of 75,000 psi, yield strength of 25,000 psi, a six percent elongation, and 27 HRB hardness.

Medical/Dental

Parmatech Corporation, Petaluma, California, USA, won the grand prize in the medical/dental category for a mechanical introducer device used in minimally invasive OB/GYN surgery (Fig. 7).

Made for STD Med, Stoughton, Massachusetts, USA, the device contains five 17-4 PH stainless steel MIM parts: right and left cover, curved needle, curved needle linkage, and centre linkage. The covers have a

complex three dimensional geometry incorporating assembly pins and slots for moving the internal parts that require smooth action for suturing.

Formed to a net shape requiring no machining, the parts are assembled by the customer who performs laser welding on the cover seam/joint. The parts are made to a density of 7.65 g/cm^3. Choosing the MIM process provided a 70% cost savings over equivalent machined parts.

Electrical/Electronic Components

The grand prize in the electrical/electronic components category was won by Capstan California Inc., Carson, California, and its customer Reliable Security Group Inc., Signal Hill, California, USA, for a soft magnetic PM alloy coil housing used in a magnetic door closer for emergency/fire protection applications (Fig. 8).

Formed as a single shape to a density of 6.8 to 6.9 g/cm^3, the new PM design replaced a three-piece assembly. Critical design features include the locations of drafts, radii, and chamfers, as well as redefining tolerances for a near-net shape part.

Secondary operations include resin impregnation and zinc plating. The one-piece design provided a 21.5% cost savings over the previous assembly.

Industrial Motors/Controls & Hydraulics

Capstan Atlantic, Wrentham, Massachusetts, USA, won the grand prize in the industrial motors/controls & hydraulics category for a PM steel alloy power take-off clutch hub (Fig. 9).

Formed to a density of 7.05 g/cm^3, the complex multi-level part replaced a machined design.

Typical properties include an ultimate tensile strength of 80,000 psi, yield strength 90,000 psi and a 92 HRB apparent hardness.

The part is designed to withstand very high torque levels in service and the flange is strong enough to resist repetitive bending fatigue.

Consumer

The grand prize in the consumer market segment category was won by Smith Metal Products, Lindstrom, Minnesota, USA, for a 17-4 PH stainless steel MIM top and bottom of an eyeglass-frame bridge (Fig. 10) made for Superfocus LLC, Van Nuys, California.

Fig. 7 Mechanical introducer device used in minimally invasive surgery

Fig. 8 Soft magnetic PM alloy coil housing used in a magnetic door closer

Featuring very thin walls, the parts form the bridge section over the nose, which also houses an actuator for changing the magnification level of the glasses. The as-sintered density is 7.6 g/cm^3.

Awards of Distinction

Automotive: Engine

SolidMicron Technologies Pte Ltd., Singapore, won the first award of distinction in the automotive-engine category for a 440C stainless steel MIM sealing seat used in a direct fuel injector assembly (Fig. 11).

Made for Magneti Marelli S.p.A. Powertrain, Bologna, Italy, the complex part has a multiple angled slot and top holes requiring precise tool design and fabrication.

The near-net-shape part has a density range of 7.54 to 7.65 g/cm^3, a tensile strength of 232,000 psi, and yield strength 203,000 psi.

The MIM process provided a 30%–40% cost savings over alternative manufacturing processes.

Fig. 9 PM steel alloy power take-off clutch hub

Fig. 10 Stainless steel MIM top and bottom of an eyeglass-frame bridge

Fig. 11 A 440C stainless steel MIM sealing seat used in a direct fuel injector assembly

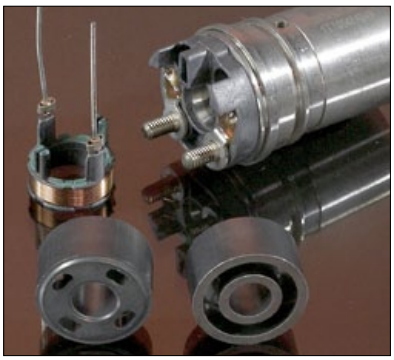

Fig. 12 Soft magnetic solenoid core used in a high-pressure diesel-engine fuel injector

Fig. 13 PM steel synchronizer hub used in a double-clutch transmission

Fig. 14 PM sinter-brazed spacer tube used in a steering-column tilt/reach assembly

Fig. 15 PM steel gear used in an output box in a tiller transmission

Automotive: Engine
Burgess Norton Mfg. Co., Geneva, Illinois, USA, won the other award of distinction in the automotive engine category for a soft magnetic solenoid core (Fig. 12) for its customer Cummins Inc.

Used in a high-pressure diesel-engine fuel injector, the core has a difficult-to-form deep pocket with high wall aspect ratios.

The part is pressed to a net-shape 7.5 g/cm^3 density. Proprietary compacting and thermal processing produce a high-strength core with superior magnetic properties.

The part is made from a high-purity iron powder with an inorganic coating electrically insulating the particles.

Fig. 16 Seven-level rack used in an industrial washing machine

Fig. 17 Six 17-4 PH stainless steel MIM parts are used in this cable-tie hand tool

Fig. 18 Porous bronze filter used in a solvent pumping purification system

Automotive: Transmission
The award of distinction in the automotive transmission category was won by the Asturias/Spain plant of the PMG Group, for a PM steel synchroniser hub made for Aichi Machine Industry Co., Ltd., Japan (Fig. 13).

The complex five-level part is used in the first and reverse gears in a double-clutch transmission. Powder Metallurgy provided a 25% cost saving over a broached steel part.

Automotive: Chassis
ACL Bearing Company, Tasmania, Australia, won the award of distinction in the automotive chassis category for a PM sinter-brazed spacer tube (Fig. 14) made for Futuris Automotive Interiors (Australia) Pty Ltd, Edinburgh, South Australia, and used in a steering-column tilt/reach assembly.

Formed to a density of 6.8 g/cm^3, the complex part has a tensile strength of 65,000 psi, 50,000 psi yield strength, 7% elongation, and 60 HRB hardness.

PM provided a 40% cost savings over fabricating the part by broaching.

Lawn & Garden/Off-Highway
Porite Taiwan Co., Ltd., Taiwan, ROC, won the award of distinction in the lawn & garden/off-highway category for a PM steel gear used in an output box in a tiller transmission (Fig. 15).

Made for Pubert SAS, Chantonay, France, the complex part is made to a density of 6.8 g/cm^3.

It has an ultimate tensile strength of 104,000 psi, 131,000 psi compressive yield strength, and a minimum 28 HRC hardness.

Appliance
Capstan Atlantic, Wrentham, Massachusetts, USA, won the appliance category award of distinction for a seven-level rack used in an industrial washing machine (Fig. 16).

Made to a density of 6.8 g/cm^3, the part has sectional density that is kept equal within 0.08 g/cm^3. The part has a minimum yield strength of 43,000 psi and typical 55,000 psi tensile strength.

PM replaced a die-cast part that needed extensive machining.

Recreation
Megamet Solid Metals, Inc., Earth City, Missouri, USA, won the award of distinction in the recreation category for a cable-tie hand tool assembly of six 17-4 PH stainless steel MIM parts (pinion, nosepiece, pawl gripper, insertable rack, cutoff cam, and short link) made for HellermannTyton, Milwaukee, Wisconsin, USA (Fig. 17).

Made to a density of 7.6 g/cm^3, the parts are produced to net shape with only four requiring minor secondary operations such as reaming and coining.

Industrial Motors/Controls & Hydraulics

Capstan California and its customer Sperry Product Innovation Inc., Woburn, Massachusetts, USA, won the award of distinction in the industrial motors/controls & hydraulics category for a porous bronze filter used in a solvent pumping purification system (Fig. 18).

The filter is gravity sintered to a density of 5.1 to 5.2 g/cm^3. The special mould design eliminates most secondary operations on the part, except for deburring the edge. It also allows step grooves to be moulded into the part.

Industrial Motors/Controls & Hydraulics

Advanced Materials Technologies Pte. Ltd., Singapore, won the other award of distinction in the industrial motors/controls & hydraulics category for 316L and 440C stainless steel parts (catch X-Z datum, catch bias Z datum, front and rear support tabs) used in an industrial printer module (Fig. 19).

Achieving a yield strength rate of 234,000 psi, the 440C tabs support and align the print head module and are subjected to impact force during printing.

The 316L catches guide and feed paper to the printing module. Choosing the MIM process over casting and machining yielded a 40% cost savings.

Electrical/Electronic Components

Smith Metal Products, Lindstrom, Minnesota, USA, won the award of distinction in the electrical/electronic components category for a 17-4 PH stainless steel lever made for Methode Electronics, Harwood Heights, Illinois (Fig. 20).

The intricate MIM part is used in a latch ejector mechanism for pluggable gigabit Ethernet connections.

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Fig. 19 316L and 440C stainless steel MIM parts used in an industrial printer module

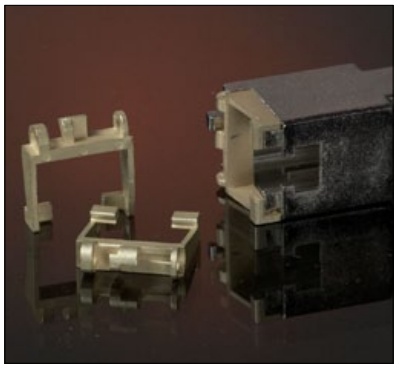
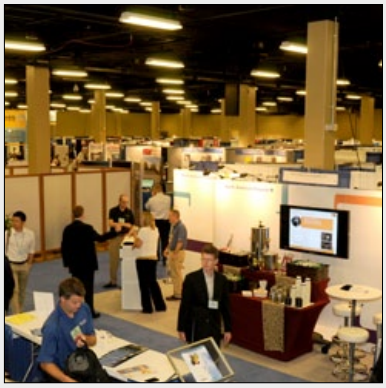


Fig. 20 Stainless steel MIM lever used in a latch ejector for Ethernet connections

PowderMet 2012 Nashville

Drew Winter, Wards Auto World Magazine

The PowderMet Welcome Reception



The PowderMet 2012 exhibition

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Call for Presentations

MIM 2013 International Conference on Injection Molding of Metals, Ceramics and Carbides

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Abstract Submission Deadline: September 30, 2012

Call for Presentations for MIM2013

Innovation in different segments of powder injection molding (PIM) is responsible for the rapid growth of this field. The PIM industry (MIM—metal injection molding; CIM—ceramic injection molding; and CCIM—cemented carbide injection molding) has estimated sales of over $1 billion and could possibly double in a span of five years.

The objective of the conference is to explore the innovations and latest accomplishments in the areas of part design, tooling, molding, debinding, and sintering of PIM parts. The conference will also focus on the developments in PIM processing of different materials including metals and alloys, ceramics, and hardmaterials.

This specialized conference is sponsored by the Metal Injection Molding Association, a trade association of the Metal Powder Industries Federation, and its affiliate APMI International. With its focus on "**Advances in Component Uniformity**," the conference is targeted at product designers, engineers, consumers, manufacturers, researchers, educators, and students. All individuals with an interest in the application of powder injection molding will be encouraged to attend.

DEADLINE FOR ABSTRACT SUBMISSION IS SEPTEMBER 30, 2012

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- Materials selection and expectations
- Review of the economic advantages of the process

This conference is sponsored by the **Metal Injection Molding Association**, a trade association of the **Metal Powder Industries Federation**

Visit mimaweb.org or mpif.org to submit an abstract

New alloy developments enhance PM aluminium application opportunities

The results of two separate Powder Metallurgy aluminium alloy developments, pursued through collaborations between GKN Sinter Metals and Dalhousie University and aimed at two diverse types of PM press/sinter application, were revealed in presentations at MPIF's PowderMet 2012 Conference in Nashville, Tennessee, June 10-13, 2012. Dr David Whittaker reviews these papers exclusively for *Powder Metallurgy Review/ipmd.net*.

Effects of zirconium additions on the sintering response of an Al-Cu-Mg PM alloy

The first of these twin papers was presented by Paul Bishop (Dalhousie University, Halifax, Nova Scotia, Canada) on behalf of his co-authors, Randy W Cooke (Dalhousie University) and Richard L Hexemer Jr. and Ian Donaldson (GKN Sinter Metals LLC, Auburn Hills, USA).

This development was aimed at enhancing the capabilities of materials for PM structural part applications. The reported work built on previous studies from the same collaborative team that had revealed the development of a new Al-Cu-Mg PM alloy (Al-2.3Cu- 1.6Mg- 0.2Sn) and specifically related to the potential benefits of making small additions of zirconium to this base alloy system.

Zirconium is recognised to confer a range of benefits in wrought Al alloys (e.g. creation of precipitation hardening, improvement in recrystallisation resistance), but its use in press/sinter PM alloys had not been previously tested.

The three powder mixes used in this study (Table 1) were all based on the emerging Al-Cu-Mg composition. Alloy A was the "base" alloy comprising air atomised elemental aluminium, inert gas atomised elemental magnesium and tin and an Al-50Cu masteralloy.

Alloy	Al	Cu	Mg	Sn	Zr	Lubricant
A	Bal.	2.3	1.6	0.2	---	1.5
B	Bal.	2.3	1.6	0.2	0.2	1.5
C	Bal.	2.3	1.6	0.2	0.2	1.5

Table 1 Nominal compositions (wt%) for the alloys studied (Courtesy MPIF)

Blend	Flow Rate (g/s)	Apparent Density (g/cc)
A	2.9	1.19
B	2.7	1.30
C	2.9	1.17

Table 2 Flow rate and apparent density results for the alloys studied (Courtesy MPIF)

Alloy	Compaction Pressure (MPa)	Green Density		Green Strength (kPa)
		(g/cc)	(% Theoretical)	
A	200	2.509	92.1	6823
	400	2.602	95.5	8438
	600	2.615	96.0	8528
B	200	2.509	92.0	6540
	400	2.604	95.5	9783
	600	2.621	96.1	9830
C	200	2.536	93.0	5359
	400	2.615	95.9	7142
	600	2.626	96.3	7279

Table 3 Green density and green strength data for the alloys studied (Courtesy MPIF)

Alloy B comprised the same ingredients together with an Al-50Zr masteralloy as the source of zirconium. Alloy C had the same bulk composition as B, but, in this case, the zirconium was prealloyed in the base aluminium powder rather than being added as a masteralloy.

Initially, it was confirmed that the Zr additions exerted no significant influence on either flow rate or apparent density of the base alloy (Table 2). Green density and green strength were assessed next for a range of compaction pressures (Table 3).

The results for alloys A and B

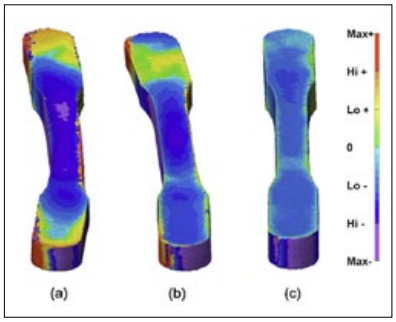

Fig. 1 Images acquired through 3D laser scanning that depict the variations in dimensional change throughout the volume of dog bone specimens (a) Alloy A, (b) Alloy B, and (c) Alloy C. (Courtesy MPIF)

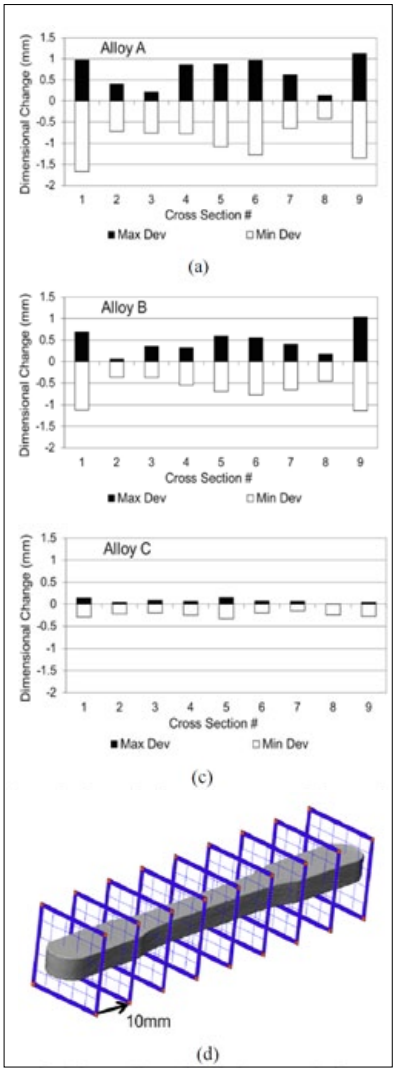

Fig. 2 Quantitative measurements of the maximum and minimum dimensional change variations (mm) acquired for 9 individual cross sections from sintered dog bones fabricated from (a) Alloy A, (b) Alloy B, and (c) Alloy C. (d) 3D image illustrating the locations of where cross sectional analyses were completed. (Courtesy MPIF)

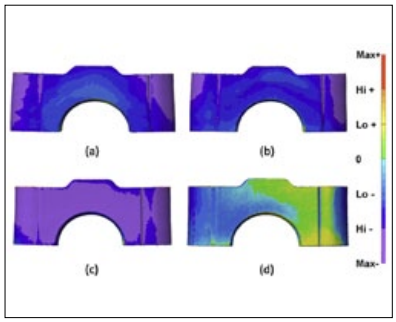

Fig. 3 Images acquired through 3D laser scanning that reveal dimensional changes in camshaft bearing caps processed from (a) alloy A, (b) Alloy B, (c) Alloy C and (d) the alloy used in commercial production of the part (AC2014) (Courtesy MPIF)

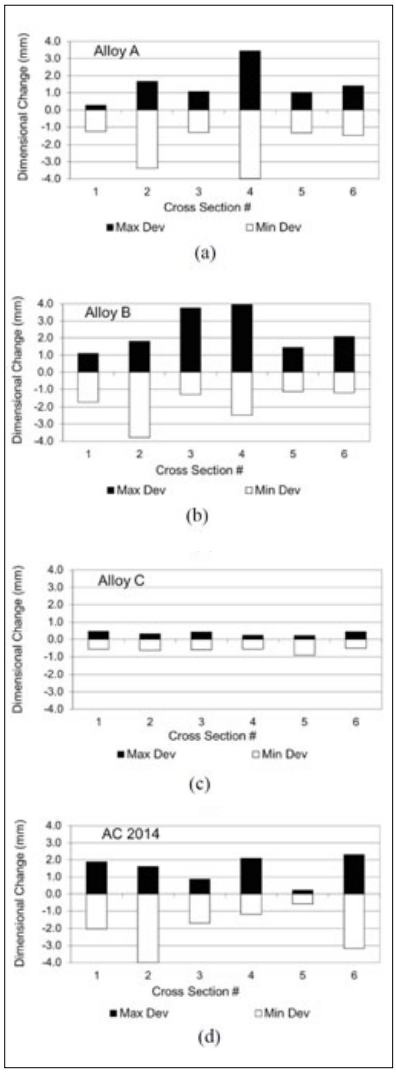

Fig. 4 Quantitative measurements of the maximum and minimum dimensional change variations acquired from vertical cross sections within camshaft bearing caps processed from (a) Alloy A, (b) Alloy B, (c) Alloy C and (d) AC2014 (Courtesy MPIF)

were fairly comparable, although the zirconium-containing alloy B showed somewhat increased green strengths. Alloy C showed a lower increase of green strength as compaction pressure was increased and it was proposed that this resulted from the pre-alloyed nature of the Zr addition.

It was found that all three alloys sintered to near full theoretical density (Table 4) and the comparative levels of sintered mechanical properties were particularly interesting (Table 5). No influence of adding Zr in masteralloy form on properties was observed. However, alloy C, with the zirconium addition in prealloyed form, showed modest increases in yield strength and UTS, but a very significant increase in elongation value to 10%.

However, the most striking advantage of using prealloyed Zr was revealed, when the dimensional changes in sintering of the three alloys were assessed.

Direct measurements on sintered TRS bars (Table 4) indicated more uniform shrinkages with alloy C than with the other two alloys, but the comparisons were shown even more dramatically using a 3-D laser scanning technique. In the maps derived from this technique, the extent of dimensional change is indicated by a colour coding.

The 3-D maps in Fig. 1 showed significant shrinkage variations and warpage in Alloy A, marginal improvements for Alloy B, but uniform shrinkage (indicated by the uniform colour of the image) and absence of warpage for Alloy C.

To quantify these comparisons, information for a number of 2-D sections of the bars was derived. These results (Fig. 2) emphasised the exceptionally small dimensional deviations observed for Alloy C.

These comparisons were further confirmed on the basis of assessing camshaft bearing cap parts, processed at the GKN Sinter Metals Condover plant from these experimental alloys. Very comparable results, to those on laboratory-processed bars, were derived from direct dimensional measurements (Table 6) and 3-D scanning (Figs. 3 and 4) and, in this case, the comparisons also included the standard commercial grade, AC-2014, used for this bearing cap application.

It was concluded that this new alloy development has potential benefits in two areas:

- It offers an enhanced combination of mechanical performance and dimensional control capability compared with standard commercial PM aluminium alloys.
- It may open up the possibility of advancing the level of geometrical complexity achievable in PM aluminium products, in order to form challenging features such as thin walls.

Development, properties, and applications for a high-thermal-conductivity sintered aluminium material

The paper presented by Richard L Hexemer Jr. (GKN Sinter Metals) on behalf of his co-authors Ian Donaldson (GKN Sinter Metals) and Logan Smith and Paul Bishop (Dalhousie University) focussed on the potential of PM aluminium products in thermal management applications such as heat sinks.

Heat sink applications represent a large market for wrought and die cast aluminium products, on the basis of a 3 to 4 cost advantage compared with the primary competing material, copper. However, to date, this market opportunity has not been tapped by PM aluminium.

Although aluminium cannot match the thermal conductivity of copper per se, the weight of a heat sink is often a design consideration and the 3 to 1 density advantage of aluminium over copper means that it can be highly competitive on the basis of specific thermal conductivity.

Table 7 compares a range of aluminium and copper materials on the basis of this parameter, which, in the final column, is normalised to denote the value for pure aluminium as 1.

In order to achieve a high thermal conductivity in sintered aluminium products, it was deemed to be necessary to minimise or eliminate porosity (i.e. to achieve a sintered density as close as possible to full theoretical density) and to avoid those alloying additions that decrease TC. These criteria led the authors to concentrate their interests on a simple Al-Mg-Sn press/sinter system.

The studies of densification of a range of Al-Mg-Sn experimental mixes, summarised in Fig. 5, led to the

Alloy	Sintered Density		Dimensional Change (%)			
	(g/cc)	(% Theoretical)	OAL	Width	Length	Spread
A	2.716	99.7	-4.52	-2.73	-1.57	2.9
B	2.719	99.7	-4.82	-2.56	-1.98	2.8
C	2.719	99.7	-3.24	-2.33	-2.13	1.1

Table 4 Sintering response for the alloys studied. All bars compacted at 200MPa (Courtesy MPIF)

Alloy	Apparent Hardness (HRE)	Yield (MPa)	UTS (MPa)	Elongation (%)
A	93.4 ± 0.1	191 ± 6	303 ± 9	7.5 ± 1.7
B	93.0 ± 0.3	185 ± 11	294 ± 9	7.9 ± 1.6
C	93.5 ± 0.1	207 ± 1	322 ± 5	10.0 ± 0.2

Table 5 Data on apparent hardness and tensile properties of the alloys studied (Courtesy MPIF)

Alloy	Density				Dimensional Change			
	Green		Sintered (%)					
	g/cc	%	g/cc	%	OAL	Width	Length	Spread
AC2014	2.47	88.8	2.46	88.6	+0.94	-1.01	-0.58	1.9
A	2.41	88.3	2.72	99.7	-3.80	-4.13	-2.47	1.7
B	2.46	90.3	2.72	99.7	-3.29	-3.89	-2.37	1.5
C	2.45	89.9	2.72	99.7	-2.94	-3.84	-2.99	0.9

Table 6 Sintering response measured for the bearing caps processed from the three experimental alloys and the commercial system AC2014 (Courtesy MPIF)

Material	Process/ Grade	Density (g/cm^3)	Thermal Conductivity (w/m-k)	Mass or specific Thermal Conductivity	
				TC / Density	normalised
Aluminium	Pure	2.7	247	91	1
Aluminium	Die Cast A380	2.7	80-100	33	0.36
Aluminium	Extruded 6061	2.7	150 – 180	61	0.67
Aluminium	Extruded 6063	2.7	190 – 210	76	0.83
Aluminium	MIM	2.5	170 – 180	70	0.77
Copper	Pure	8.9	398	45	0.49
Copper	Wrought C11000	8.9	380 – 390	43	0.47
Copper	Cast C81100	8.9	340 – 350	39	0.43
Copper	Cast C83400	8.7	180 – 190	21	0.23
Copper	MIM	8.5	320 – 330	38	0.42

Table 7 Thermal conductivities of selected aluminium and copper materials (Courtesy MPIF)

Material	Process/Grade	Density (g/cm^3)	Thermal Conductivity (w/m-k)	Mass or specific Thermal Conductivity	
				TC / Density	normalised
Aluminium	Pure	2.7	247	91	1
Copper	Pure	8.9	398	45	0.49
	Commercial				
Aluminium	PM ACT1-2014	2.6	144	55	0.60
	Metal Matrix				
Aluminium	PM Al MMC1	2.7	137	51	0.56
	New PM				
Aluminium	PM TC2000-1.5	2.7	210 – 230	81	0.89
Aluminium	PM TC2000-1.0	2.7	240 - 250	90	0.99

Table 8 Thermal conductivities of existing and the newly developed aluminium PM alloys (Courtesy MPIF)

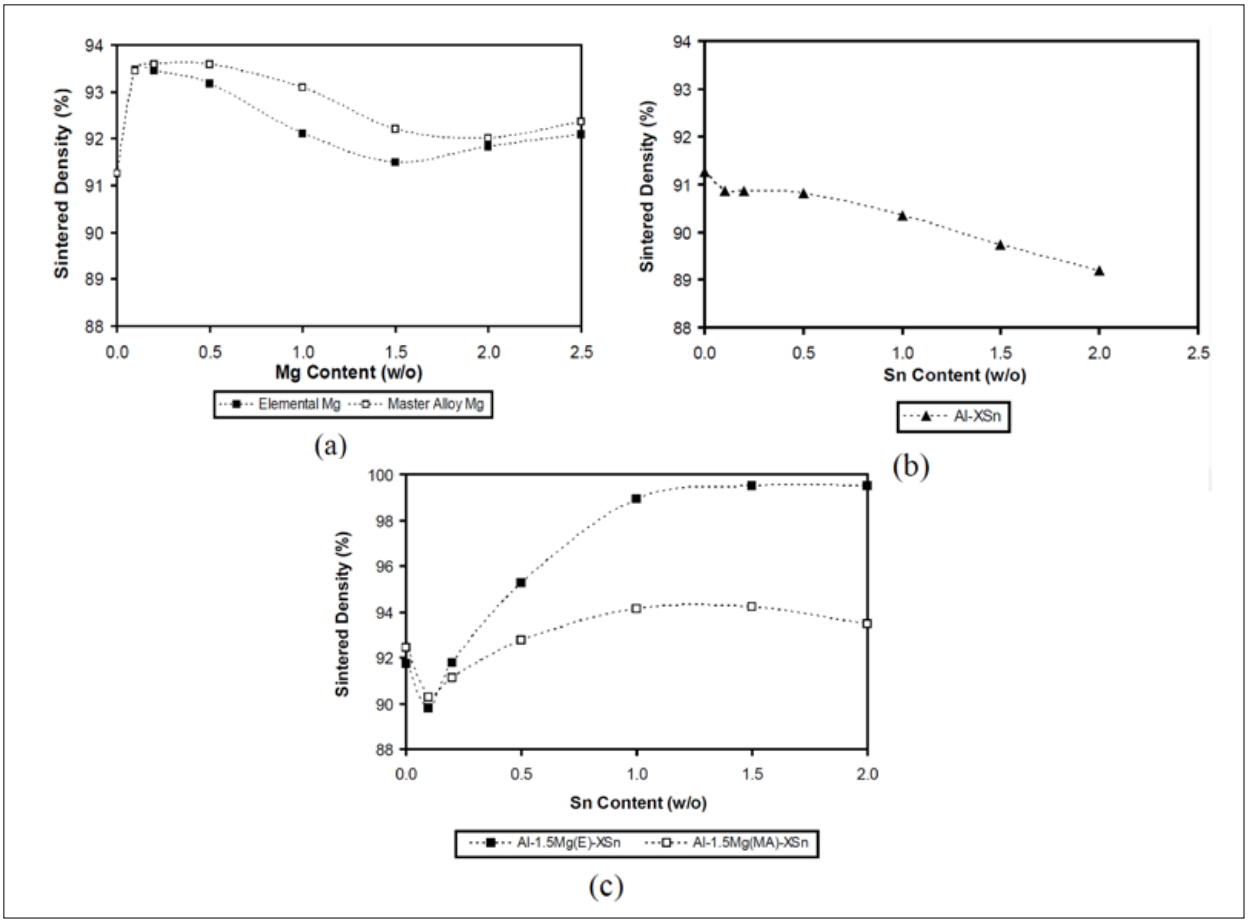

Fig. 5 Effects of Mg (a), Sn (b) and their combination (c) on the sintered density of aluminium PM compacts (data extracted by the authors from MacAskill et al) (Courtesy MPIF)

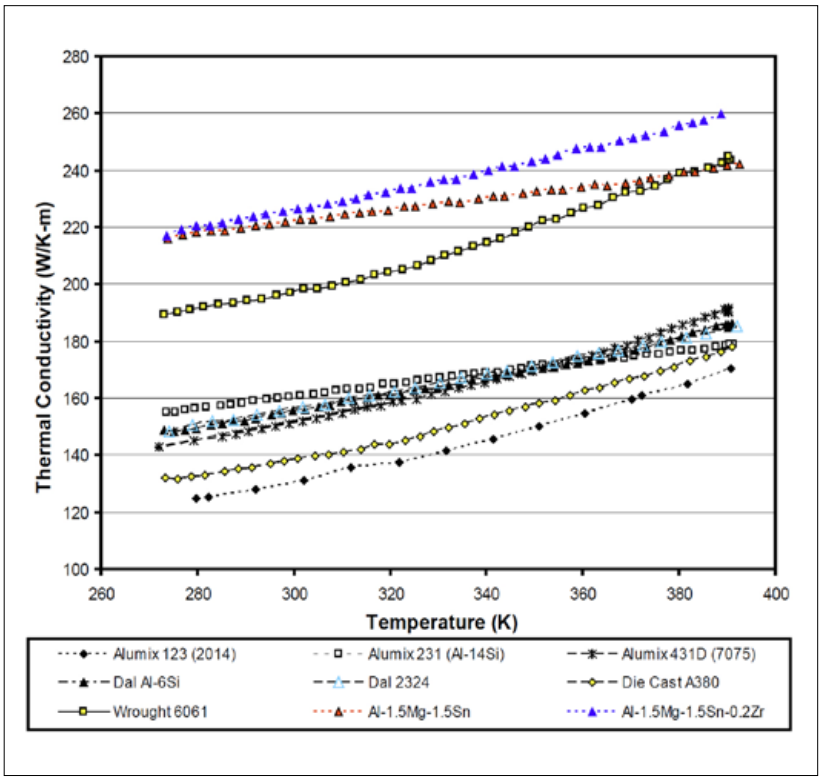

Fig. 6 Thermal conductivities of selected aluminium PM, wrought and die cast materials. (Courtesy MPIF)

conclusions that:

- Magnesium was more effective as an elemental addition than as a masteralloy.
- Two alloy compositions, Al-1.5Mg-1.5Sn (wt %) and Al-1.0Mg-1.0Sn (wt %) should be selected for development. These two compositions were designated as PM TC2000-1.5 and PM TC2000-1.0 respectively.

Fig. 6 demonstrates that the first of these alloys provides thermal conductivity that is superior to the levels achievable with a range of standard wrought and die-cast aluminium materials.

This figure also shows that, if elevated temperature thermal conductivity is a significant design consideration, then this property can be further enhanced by the use of a Zr-prealloyed Al as the base powder for the alloy.

The specific thermal conductivities of the newly developed alloys are compared with those of existing materials in Table 8. The data in this

table demonstrate the superiority, in this context, of these alloys over established commercial PM aluminium grades and, indeed, the PM TC2000-1.0 grade offers the same TC as pure aluminium.

Two further property parameters have been considered in this development:

- Coefficient of thermal expansion (CTE) was measured for the new alloys and was found to be in line with pure Al. Further, previous work had shown that the level of this property could be lowered by the addition of ceramic materials that have low CTE. Lower CTE is a desirable attribute for heat-sinks when matching with low expansion substrates such as silicon.
- Tensile properties were measured on dog-bone test-pieces. These properties are presented in Table 9. Although, these properties are relatively low compared to established PM aluminium alloys, they are considered to be sufficient for heat sink applications. However, the incorporation of ceramic additions was again considered to be a potential means of improving these mechanical properties.

The addition of ceramics in two forms was therefore studied – a separate addition of silicon carbide (SiC) or the in-situ formation of aluminium nitride (AlN) during sintering.

The results reported in Table 10 demonstrate that additions of up to 15% AlN bolster mechanical properties while simultaneously reducing CTE.

The influence of these ceramic additions on thermal conductivity of the new PM alloys is still under investigation but, given that the ceramic additions have intrinsically high thermal conductivity compared with aluminium, the authors have a high level of confidence that a beneficial influence will also be observed in this context, provided that a good interface between the reinforcement and the matrix is created.

Overall, it can be concluded that this work has provided GKN Sinter Metals with a new suite of PM aluminium grades, with which to attack this significant new market opportunity.

Alloy	w/o Sn	Temper	UTS (MPa)	YS (MPa)	Elongation (%)	Young's (E)
Al-1.5Mg	0	T1	103	50	3.62	49.7
Al-1.5Mg-0.1Sn	0.1	T1	103	47	4.44	46.3
Al-1.5Mg-0.2Sn	0.2	T1	113	41	8.69	21.8
Al-1.5Mg-0.5Sn	0.5	T1	118	38	9.65	39.6
Al-1.5Mg-1.0Sn	1	T1	116	37	13.98	16.0
Al-1.5Mg-1.5Sn	1.5	T1	112	39	14.80	19.4
Al-1.5Mg-2.0Sn	2	T1	100	37	12.49	21.1

Table 9 Tensile properties of Al-1.5Mg-xSn systems (data extracted by the authors from MacAskill et al) (Courtesy MPIF)

AlN Addition (v/o)	Matrix Alloy	Temper	UTS (MPa)	YS (MPa)	Elongation (%)	Young's (E)
0	Al-1.5Mg-1.5Sn	T1	112	39	14.80	19.4
2	Al-1.5Mg-1.5Sn	T1	97	54	2.32	26.8
5	Al-1.5Mg-1.5Sn	T1	108	57	2.63	45.0
10	Al-1.5Mg-1.5Sn	T1	121	62	4.49	31.5
15	Al-1.5Mg-1.5Sn	T1	142	76	3.80	45.1
25	Al-1.5Mg-1.5Sn	T1	92	90	0.40	40.7
SiC Addition (v/o)	**Matrix Alloy**	**Temper**	**UTS (MPa)**	**YS (MPa)**	**Elongation (%)**	**Young's (E)**
0	Al-1.5Mg-1.5Sn	T1	112	39	14.80	19.4
2	Al-1.5Mg-1.5Sn	T1	108	41	9.63	21.2
5	Al-1.5Mg-1.5Sn	T1	108	47	6.66	23.9
10	Al-1.5Mg-1.5Sn	T1	88 5	1	2.42	31.2

Table 10 Influence of the addition of AlN and SiC on tensile properties of Al-1.5Mg-1.5Sn (Courtesy MPIF)

Author

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Binder/lubricant developments enhance Powder Metallurgy part quality and strength

A presentation in the Special Interest Programme on Lubrication Science at the MPIF's PowderMet 2012 Conference, June 10-13, Nashville, Tennessee from Francis Hanejko (Hoeganaes Corporation, USA), on behalf of his colleagues, William Tambussi and Jeanne Hooker, emphasised the message that the development of binder/lubricants has brought a range of compaction process control and dimensional control benefits, and has been an important enabler in the enhancement of product densities and strength levels through processes such as Warm Die Compaction. Dr David Whittaker reviews this paper exclusively for *Powder Metallurgy Review/ipmd.net*.

Traditionally, the PM structural parts industry has had a love-hate relationship with pressing lubricants. They are vital in terms of protecting components and tooling during the forming and ejection processes, but can cause a range of process problems during sintering.

PM's initial approach to pre-mixing, the simple mixing of elemental ingredients, was simple and cost effective but gave potential problems with segregation in mixes. Next, diffusion alloying appeared as an effective means of preventing segregation of the metallic alloying elements and improving control over dimensions and strength. However, this approach could do nothing about segregation and dusting problems associated with graphite and lubricant additions. Hence, binder treatments were developed as a means of tackling these issues.

Initially, oils were investigated as a means of controlling dusting. This was a simple approach but carried a number of disadvantages; mixes were not totally dry, flow rate and apparent density tended to change with time and also, generally, apparent density was reduced.

"Traditionally, the PM structural parts industry has had a love-hate relationship with pressing lubricants"

These issues stimulated interest in the use of polymer bonding (in Hoeganaes Corporation's case, ANCORBOND® processing). The first generation of such developments produced the targeted benefits of improved flow

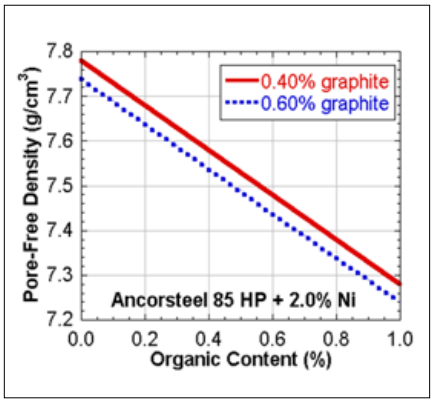

Fig. 1 The effects of graphite and organic contents on Pore-Free Density (As presented at PowderMet 2012, 10-13 June 2012, Nashville, USA. Courtesy Hoeganaes)

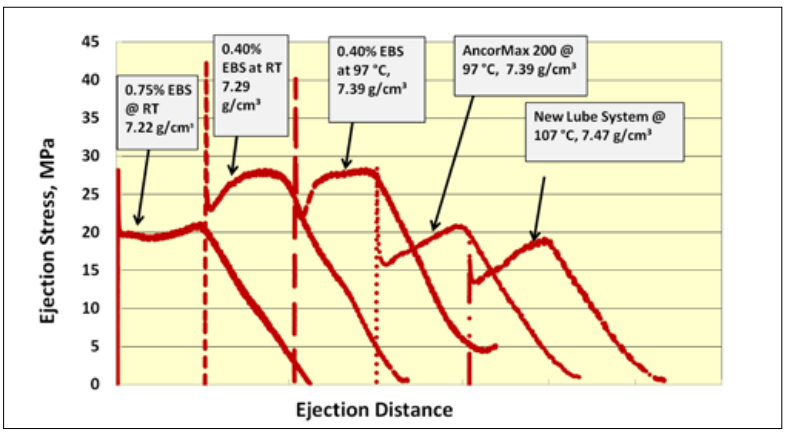

Fig. 2 Comparison of ejection characteristics of various lubrication systems (all compaction at 830 MPa) – Material FN-0205 (As presented at PowderMet 2012, 10-13 June 2012, Nashville, USA. Courtesy Hoeganaes)

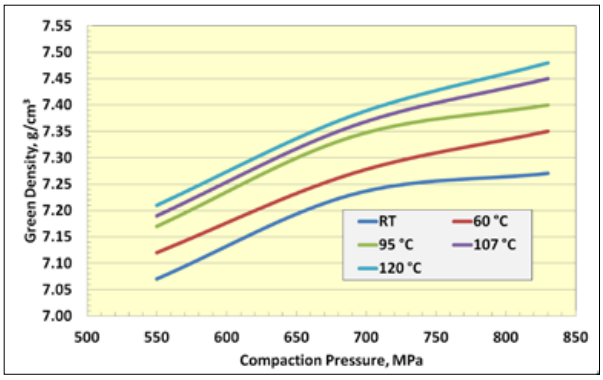

Fig. 3 Effect of temperature on green density. Material FLN2-4400 (As presented at PowderMet 2012, 10-13 June 2012, Nashville, USA. Courtesy Hoeganaes)

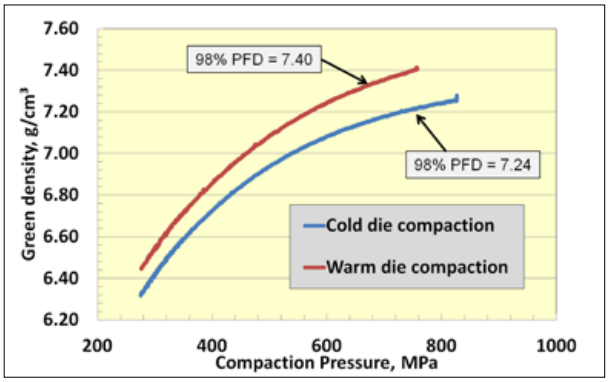

Fig. 4 In-die density vs. compaction pressure. Material FLN2-4405 (As presented at PowderMet 2012, 10-13 June 2012, Nashville, USA. Courtesy Hoeganaes)

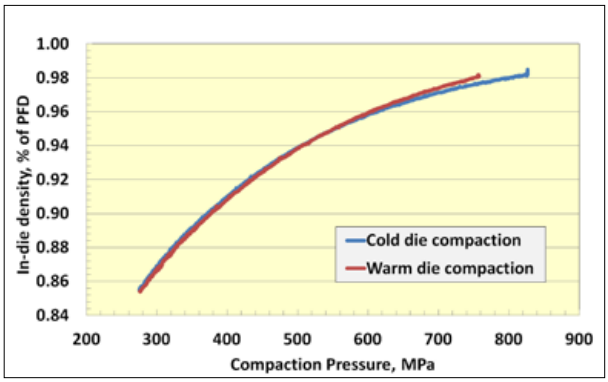

Fig. 5 In-die PFD vs compaction pressure. Material FLN2-4405 (As presented at PowderMet 2012, 10-13 June 2012, Nashville, USA. Courtesy Hoeganaes)

rates, reduced dusting and higher apparent densities, but, because the binders were in addition to the normal pressing lubricants, the higher total organic content in mixes restricted pore-free density and therefore achievable green density levels.

The second generation of developments therefore concentrated on finding polymer additions that can deliver both bonding and lubrication.

In early lubrication trials, it soon became apparent that maximum achievable green density was dependent on a parameter, referred to as Pore Free Density (PFD) and defined as the density of a green compact if all of the porosity could be removed.

The low density additions of graphite and lubricant/binder have particularly negative effects on PFD (Fig. 1). It was also observed that the practical limit of green density is around 98% of PFD (beyond this limit, formation of micro-laminations is likely) and, hence, the main potential route to higher green densities lay in raising PFD. Potential means of achieving this aim include:

- Working with lower lubricant/binder levels
- Raising compaction die temperature.

The development of further generations of binder/lubricants, often tailored for use in Warm Die Compaction, have contributed to and continue to contribute to furthering the above objectives.

The proprietary binder/lubricant, AncorMax 200, specifically developed for Warm Die Compaction at a tooling temperature of around 93°C, is generally used at a 0.4 wt% addition level whereas a "new lube system" was revealed by the author, which is designed to be used at a level of only 0.25 wt%. and for use at a tooling temperature of around 107°C.

Fig. 2 demonstrates that these binder/lubricants, used at these addition levels and tooling temperatures, provide superior ejection properties to 0.75 wt% EBS in room temperature compaction and 0.4 wt% EBS in compaction at room temperature or at 97°C.

Work reported by several major powder suppliers has shown that the "real" green density increases as compaction temperature increases and this is amply demonstrated by the Hoeganaes Corporation data in Fig. 3.

It has often been postulated that this effect is related to a reduction of flow stress of the ferrous powder grade over this temperature range. However, it is clear that the use of a binder/lubricant, specifically designed to operate effectively at the increased temperature levels and used at lower addition levels, must also be playing a significant role, as evidenced by the comparison between Figs. 4 and 5.

In these figures, the powder mix used in cold compaction contained 0.75 wt% Acrawax, whereas that used in Warm Die Compaction contained only 0.4 wt% of a proprietary binder/lubricant. The two compressibility curves appear very different, when plotted in terms of green density in Fig. 4, but virtually coincide when plotted in terms of PFD in Fig. 5.

The "new lubricant system" under development is particularly interesting in that it offers the potential, for the first time, to lower the premix organic content to only 0.25 wt%. This allows PFD to be increased by 0.07 to 0.10 wt%. By employing a part ejection temperature of 107°C (225°F), it has been proved feasible, in laboratory pressing trials, to achieve green densities of up to around 7.47 g/cm³ and limited prototype production has shown similar results. As demonstrated in Fig. 2, this is accompanied by a reduction in ejection forces.

Limited work with a Double Press-Double Sinter process at a high compaction pressure of 830 MPa has also shown that the generation of sintered densities over 7.6 g/cm³ is feasible with this system.

www.hoeganaes.com

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