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WINTER 2013

POWDER METALLURGY REVIEW

TITANIUM POWDER METALLURGY

PM STANDARDS

EURO PM2013 CONFERENCE REPORT

ipmd.net

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AUTOMOTIVE HEAVY INDUSTRY AEROSPACE

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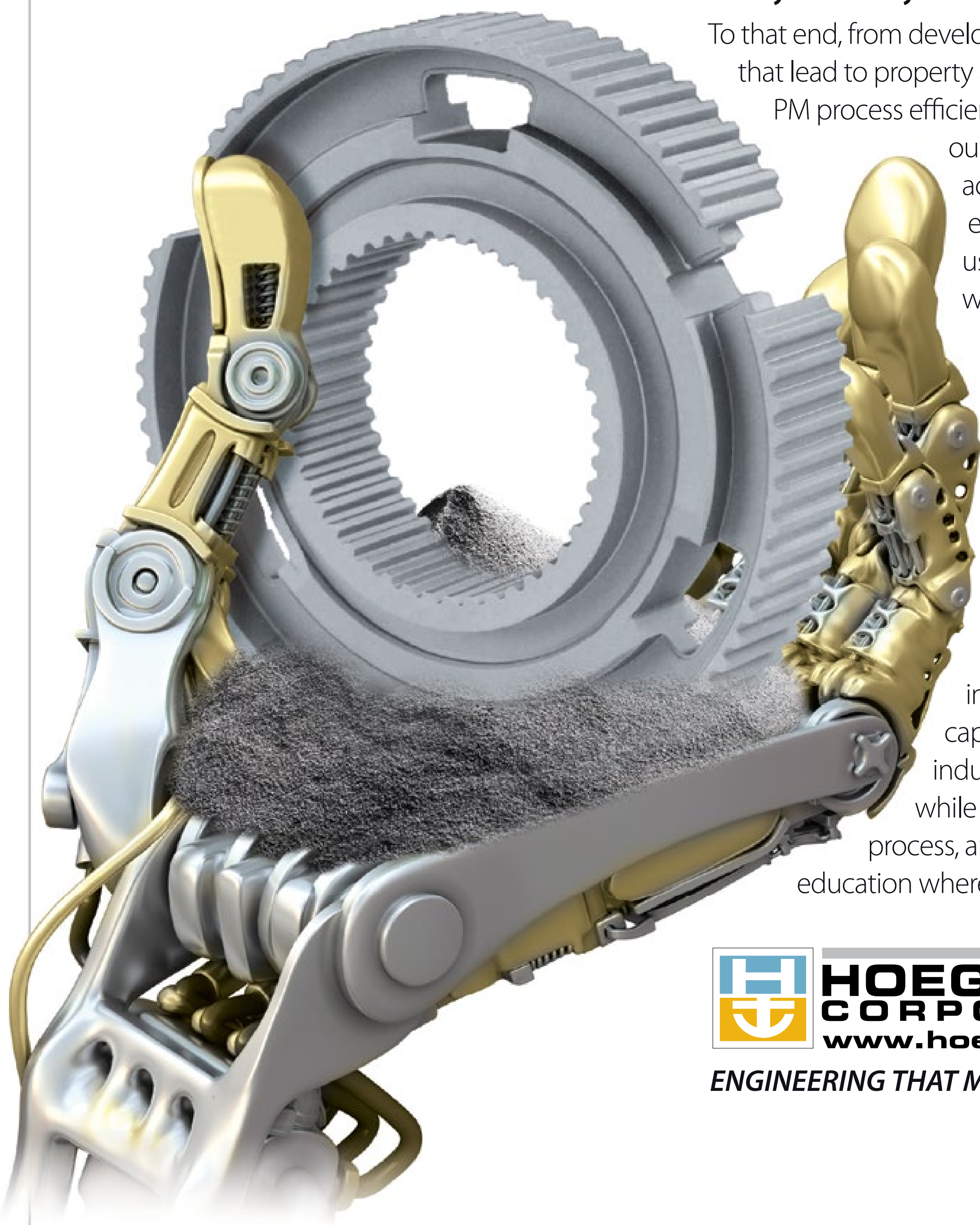

The potential of powder metallurgy is only limited by one's imagination…

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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

Looking ahead to 2014: New challenges and new applications

Welcome to the latest issue of *Powder Metallurgy Review*. We are delighted with the reception that our publication has received over the past year and the combination of print and online distribution has enabled us to achieve a significant and growing global readership.

The Autumn 2013 issue received additional distribution at the Euro PM2013 Conference in Sweden and the very successful APMA 2013 Conference in Xiamen, China. Inovar Communications was the only publishing company to exhibit at both events, promoting its publications *Powder Metallurgy Review* and *Powder Injection Moulding International*.

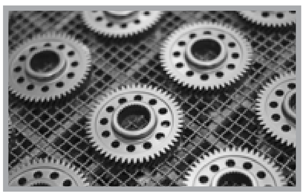
Interest in the potential of titanium PM continues to grow and in this issue a comprehensive review by Dr F H (Sam) Froes demonstrates how PM is an attractive option for the cost effective production of high integrity titanium components for a wide variety of application sectors (page 29).

The importance of national and international PM standards and the advantages they offer the industry cannot be underestimated. Dr Brian James reviews the development of PM standards over the past 50 years and highlights the organisations that are active today (page 45).

A number of technical highlights from the Euro PM2013 conference are reviewed by Dr Georg Schlieper (page 57) and we present the latest innovations and applications from Japan where the JPMA has announced its 2013 PM Award winners (page 67).

Looking ahead to 2014, we are working on an exciting and dynamic editorial schedule and look forward to meeting many of our readers at the various national and international PM events taking place throughout the year, with the highlight of course being the PM2014 World Congress in Orlando, Florida.

Paul Whittaker
Editor, *Powder Metallurgy Review*

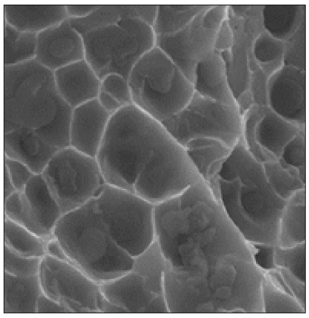


Cover image
Stress and weight optimised Powder Metallurgy transmission gears prototyped by Höganäs AB during the 2013 PoP day, September 18 2013

Winter 2013

POWDER METALLURGY REVIEW

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in this issue

regular features

Backed by 65 years of thermal processing expertise, Ipsen's new sintering and debinding furnace, TITAN® DS, upholds our reputation for quality. Ipsen delivers the best through better performance and better features for less cost, bringing the MIM and Powder Metallurgy industry one step forward.

Benefits

- Reduced door-to-door cycle time
- Unbeatable price-to-volume ratio for specialized MIM furnaces
- Precise process control for consistent part quality
- Short delivery time with rapid start-up
- One global standard
- Modular design for ease of production flow optimization

Technical Information

- Work zone size: 915 mm x 915 mm x 1,220 mm (36" x 36" x 48")
- Hearth gross load weight capacity: 2,700 kg (6,000 lbs)
- Maximum operating temperature: 1,400°C (2,550°F)
- Temperature uniformity: better than +/- 5°C (+/- 10°F)
- Ultimate vacuum level: < 7 Pa (50 microns)
- Nitrogen, hydrogen and argon partial pressure for operation up to 13 mbar (10 Torr)
- Internal nitrogen or argon gas cooling up to 2 bar
- 3 heat trim zones

Visit www.IpsenUSA.com/TITANDS
to learn more about TITAN DS.

www.IpsenUSA.com/TITANDS

Ipsen

Hard Work Wins

industry news

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

Stackpole sold to US and Chinese private equity firms

Stackpole International, headquartered in Ontario, Canada, has been bought by New York based private equity firm Crestview Partners, along with CITIC Capital, a private equity firm based in China. Members of Stackpole's management have also participated in the sale from current owners Sterling Group and Current Capital LLC, both US based private equity firms. Details of the deal were not disclosed

Stackpole is a manufacturer and supplier of highly engineered oil-pumps and powdered metal components to automotive original equipment manufacturers and tier 1 suppliers.

Peter Ballantyne will continue to lead Stackpole as President and CEO and as a member of the company's board of directors. Joining Ballantyne on the board will be representatives from Crestview and CITIC, as well as two directors with significant global automotive industry experience, Sir Nick Scheele, former COO of Ford Motor Company, who will serve as the company's new Chairman and Jason Luo, current CEO of automotive supplier Key Safety Systems.

Tom Murphy, Co-Founder of Crestview, stated "We are excited about partnering with management and veteran industry executives to help drive Stackpole's next stage of growth. Peter and his team have done a tremendous job managing Stackpole, and the company is poised to expand internationally, capitalise on the increasing trend towards vehicle fuel-efficiency and continue its market leadership in the automotive supply industry."

"We look forward to Stackpole's exciting next chapter in partnership with Crestview and CITIC. We believe Crestview's experience investing in and growing automotive companies, CITIC's experience helping businesses like ours grow in China, and Sir Nick Scheele and Jason Luo's breadth of global experience in the automotive industry, will add significant insight to the company in supporting our customers and executing on Stackpole's future growth plans," added Ballantyne.

www.stackpole.com

Higher demand in North America pushes up PM sales at Hitachi

Japan's Hitachi Chemicals reported that from April 1 to September 30, 2013, sales in its "Functional Materials" and "Advanced Components & Systems" divisions increased by 3.8% compared with the same period last year to Yen 243,046 billion ($2.465 billion). Net income increased by 64.3% to Yen 14,787 billion ($150 million), due to extraordinary profit from the compensation payment from the Tokyo Electric Power Company after the Fukushima Dai-ichi Nuclear Power Station accident.

The Advanced Components and Systems division includes PM parts, bearings and sintered friction materials produced in Japan, Thailand, China and North America. Sales of this division totalled Yen 111,690 billion ($1.133 billion), an increase of 2.2% on the previous financial year. The increase for PM parts sales was attributed to higher demand in North America.

www.hitachi-chem.co.jp

GKN Powder Metallurgy sales up 13% in third quarter

Figures released in GKN plc's interim management statement show that the GKN Group made good progress in the three months ended 30 September 2013, with sales totalling £1,865 million, a 16% increase over the same period in 2012, including 6% organic growth. The increase in sales from acquisitions less divestments was reported as £145 million.

"The third quarter showed good progress, supported by automotive demand in China and North America and sustained high output levels in commercial aerospace. GKN Aerospace Engine Systems made a strong contribution to the Group's 34% growth in profit before tax," stated Nigel Stein, Chief Executive, GKN plc.

Third quarter sales in the group's GKN Powder Metallurgy division were up 13% to £234 million (2012: £208 million), with organic sales growth of 10%, outperforming automotive production in both Europe and North America, stated the report. Trading profit increased to £23 million (2012: £20 million) at a margin of 9.8% (2012: 9.6%).

Year to date figures for GKN Powder Metallurgy were also up on the previous year with the first nine months sales totalling £714 million, up from £673 million in 2012.

The report stated that global light vehicle production in the third quarter, of around 20 million vehicles, was 4% ahead of the comparable period in 2012 with good growth in China (+9%) and North America (+6%) and more modest growth in Europe (+2%) and Japan (+2%). Brazil (+7%) and India (+5%) continued to be volatile.

Automotive and commercial aerospace markets are expected to remain robust with industrial and military aerospace markets soft, the company stated. The Group expects 2013 overall to show another year of good progress helped by the contribution of GKN Aerospace Engine Systems.

www.gkn.com

Carpenter signs agreement with UTC and announces new superalloy powder facility

Carpenter Technology Corporation has announced a multi-level agreement with United Technologies Corporation (UTC), through its Pratt & Whitney Division, which includes licensing technology associated with the production of superalloy powders and a long-term supply agreement. Carpenter also announced plans to build a new superalloy powder facility in Alabama, USA, directly opposite the company's nearly completed $518 million ultra-premium product manufacturing plant.

The superalloy powder facility is expected to begin production in late 2015. Once the facility is qualified by Pratt & Whitney following construction, Carpenter will supply Pratt & Whitney with superalloy powder for use in aircraft engines for up to 20 years. "The capital cost of this project falls within the annual $120 million capital spend guidelines that were previously outlined for the period following the completion of the main Athens plant," stated Tony Thene, Carpenter's Chief Financial Officer.

Global demand for superalloy powder is expected to grow substantially as aircraft engine temperatures increase. Carpenter's entrance into this market segment reflects its confidence in superalloy powder demand for additional applications such as those used in energy and additive manufacturing, stated the company.

In addition to the powder supply agreement, UTC's aerospace business units (Pratt & Whitney, Pratt & Whitney Canada Corp., UTC Aerospace Systems and Sikorsky Aircraft Corporation) have agreed to purchase alloy steel bar/billet, nickel superalloy billet, stainless bar/billet, and strip laminate products from Carpenter for a period of ten years.

www.cartech.com

Sandvik's performance affected by strong Swedish Kronor

Sweden's Sandvik Group has reported that invoiced sales were down 9% to SEK 20.4 billion in the third quarter 2013 when compared with Q3 2012, and down 6% over the first nine months of 2013 to SEK 65.6 billion.

"The strong Swedish krona (SEK) adversely affected earnings by SEK 250 million in the third quarter and by SEK 900 million SEK in the first nine months of the year. Nevertheless, operating profit totalled SEK 2,531 million SEK, or 12.4% of invoiced sales in the seasonally weakest quarter of the year, despite negative metal price effects and, declining sales and production rates," stated Sandvik's President and CEO Olof Faxander when presenting the company's third quarter results.

Sandvik's Machining Solutions division, which includes the Sandvik Coromant cutting tool product area, showed 4% higher sales at SEK 6.9 billion. The slightly positive demand trend observed earlier in the year in Europe was also noted in the third quarter.

Asia improved from a low base while demand in North America slowed somewhat from a high level. The acquisition of the remaining 51% of the shares in cutting tool producer Precorp Inc. was announced during the quarter, and in September, the Sandvik Coromant product area introduced the GC4325 insert grade, a cemented carbide (hardmetal) breakthrough product designed for steel turning applications.

The Sandvik Venture division, which includes the newly created product area Sandvik Hyperion combining Diamond Innovations and Sandvik Hard Materials, saw invoiced sales decline by 8% to SEK 1.25 billion in the 3rd quarter. Operating profit for Sandvik Venture amounted to SEK 199 million, down 22% on the same period last year. The Hyperion product area provides products and services within applied materials, such as super-hard and hard materials, based on cemented carbide, cubic boron nitride, and synthetic diamond.

www.sandvik.com

Sumitomo Electric Industries posts strong half-year results

Sumitomo Electric Industries Ltd (SEI) based in Itami, Japan, recorded a 16.7% increase in net sales to Yen 1,217 billion ($12.345 billion) for the first half (April to September) of its 2013/2014 financial year. Net income soared by 63% to Yen 25,803 billion ($261.7 million).

SEI's "Industrial Materials & Others" division, which includes the production of cemented carbides, Powder Metallurgy parts, and the fully owned A.L.M.T. subsidiary which produces W, Mo, heavy metal, thermal management materials, ceramics, diamond tools and hardmetals, reported a 7% increase in first half year sales to Yen 147,187 ($1.493 billion).

PM part sales increased by 5.6% to Yen 24.2 billion ($245 million) whilst hardmetal sales increased by 13.1% to Yen 39.6 billion ($402 million). A.L.M.T. enjoyed an increase of 8.6% to Yen 20.2 billion ($205 million). Special steel wires made up the remaining Yen 35.5 million in this division of SEI.

SEI is forecasting a 22% increase in group sales for the whole of the current financial year to Yen 2,500 billion ($25.4 billion) and a 10.2% increase in full year sales for the Industrial Materials division. The company has expanded hardmetal production at its new factory in Hokkaido, Japan, with super efficient production lines for cemented carbide inserts, and began production of hardmetal cutting tools in Indonesia.

SEI has also established a manufacturing and marketing joint venture with WLK Group and Santini Group for sintered parts in Indonesia. A.L.M.T. is reported to be accelerating new product development in the electronics field, including precision diamond tools essential for semiconductor nano- and microprocessing.

The new diamond tools are made from ultra-fine high-hardness nano-polycrystalline diamonds using ultra-fine grains of several tens of nanometres. The diamond tools are produced using a new proprietary process involving ultra-high voltage.

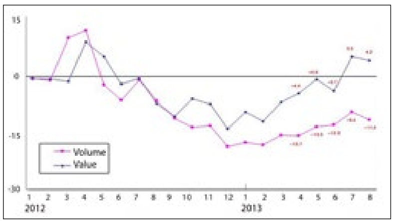
www.global-sei.com

Japan's hardmetal production slows

Following a slump in Japan's production of cemented carbide in 2012, the first half of 2013 witnessed a steady recovery. However figures published by the Japan Cemented Carbide Tool Manufacturers Association (JCTMA) show a dip in that recovery in August, with a drop in production volume in that month to 410 tonnes, down 11.4% compared with the same month in 2012.

In 2012 production value for all cemented carbide products in Japan was Yen 276,542 million ($2.818 billion). In terms of volume there was a 9.3% drop to 5340 metric tonnes for the year.

www.jctma.jp



Monthly changes in the value of shipments and volume of tool and carbide alloy production in Japan

Kennametal to buy ATI's tungsten materials business for $605 million

Kennametal Inc. has announced an agreement to acquire the Tungsten Materials Business of Allegheny Technologies Incorporated (ATI) for $605 million. ATI's Tungsten Materials Business, with around $340 million in annual sales, produces tungsten powder, tungsten heavy alloys, tungsten carbide materials and carbide cutting tools. The business has approximately 1175 employees across 14 operating facilities globally and consists of two divisions, ATI Firth Sterling and ATI Stellram.

The transaction has been approved by both companies' boards of directors and is expected to close before the end of 2013, subject to customary regulatory approvals and closing conditions.

"The addition of the expanded material and tooling technologies of ATI's Tungsten Materials Business will enable us to offer more to our customers around the world. We look forward to building on our respective strengths to accelerate growth while generating even greater value for our business and ultimately our shareholders," stated Kennametal Chairman, President and CEO Carlos Cardoso.

According to Kennametal, this acquisition is aligned with the company's growth strategy and positions the group to further diversify its portfolio. The company expects to capitalise on the material technology capabilities, engineered components and tooling products of ATI's Tungsten Materials Business to expand its presence in the aerospace and energy markets.

The ability of ATI's Tungsten Materials Business to produce critical materials from recovered tooling and scrap will enhance Kennametal's material sourcing and accelerate previously announced plans to expand capacity and develop an advanced tungsten carbide recycling facility in the US.

In addition, the acquisition will expand Kennametal's tooling portfolio in the areas of metal cutting and metal finishing technologies, through brands such as Stellram Products, Garryson Products and Landis Products.

www.ATImetals.com
www.kennametal.com

Verder Group acquires furnace manufacturer Gero

Gero Hochtemperaturöfen GmbH & Co. KG located in Neuhausen, near Stuttgart, Germany, has recently been acquired by the Verder Group, joining the company's Scientific Division.

Gero manufactures a wide range of furnaces for a number of applications including Powder Metallurgy and Metal Injection Moulding. Furnaces are suitable for both industrial and research processes, with models capable of operating up to 3000°C. The company generates a turnover of some €7 Million.

"With the acquisition of Gero, the Scientific Division of the Verder Group now offers the complete range of high temperature furnaces up to 3000°C," stated Dr Jürgen Pankratz, Director of the Verder Scientific Division. "Gero's portfolio complements the line of laboratory and industrial furnaces and ovens offered by the British manufacturer Carbolite Ltd., also part of the Verder Group."

www.gero-gmbh.de

Berkshire Hathaway buys remaining stake in Iscar as earnings soar in first half of 2013

Warren Buffett's Berkshire Hathaway Inc. (BHI) reported net earnings attributable to Berkshire shareholders of $9.433 billion in the first half of 2013, a 48% increase compared with the same period last year. BHI owns a number of diverse businesses including insurance, freight rail transportation, utilities and energy, finance, services and retailing, and manufacturing. The manufacturing arm of the company includes IMC International Metalworking Companies (Iscar), an industry leader in the field of cemented carbide (hardmetal) metal cutting tools. BHI chairman is billionaire Warren E Buffet with Charles T Munger acting as vice-chairman.

Investment in the cemented carbide sector

Warren Buffett made the decision to invest in the metal cutting tool sector seven years ago when BHI bought 80% of IMC (Iscar) for around $5 billion from the Wertheimer family which founded the business in Israel 60 years ago. It was the first acquisition by BHI outside of the United States. The Israeli carbide producer based in Tefen, northern Israel, soon made positive contributions to BHI financial results. Although IMC is not obliged to make public its financial results, it is estimated to have achieved sales of more than $3 billion in 2011 with profits close to $1 billion, more than twice what they were in 2005.

BHI had in the meantime added a number of other leading cemented carbide producers to the IMC stable: notably Ingersoll (USA), Metaldur (Switzerland), Microtools (Israel), Outiltec (France), UOP Spa (Italy), TaeguTec (Korea) and Tungaloy (Japan). Today the IMC group has over 10,000 employees in 140 subsidiaries in 61 countries.

In May 2013 Berkshire Hathaway purchased the remaining 20% shareholding in Iscar for a quoted $2.05 billion giving the Israeli company a total valuation of around $10 billion. "Since the time IMC entered our lives, my partner Charlie Munger and I have enjoyed Berkshire's association with the company, the Wertheimer family and the company's management team," stated Buffett at BHI headquarters in Omaha, Nebraska.

"As you can surmise from the price we're paying for the remaining interest, IMC has enjoyed very significant growth over the last seven years, and we are delighted to acquire the portion of the company that was retained by the Wertheimer family when IMC first became a member of the Berkshire group of companies.

We look forward to continuing our stewardship of this unique company founded by the Wertheimer family in Israel 60 years ago and nurtured into a truly global enterprise," Buffett said in the statement.

Eitan Wertheimer stated, "We are very pleased that IMC has found a permanent home in Berkshire Hathaway, which fully appreciates the unique nature of the global Israeli enterprise that we have created and that is committed to remaining true to that heritage in every way, building on and continuing our historic success and special culture. The growth experienced by IMC since the 2006 Berkshire transaction validates the faith that Warren [Buffett] and Charlie [Munger] showed in our business and the special people in Tefen, Israel and around the world who have made our success possible."

www.berkshirehathaway.com
www.iscar.com

Change of management at Schunk and ceremonial farewell for Gerhard Federer

The Schunk Group, based in Heuchelheim, Germany, celebrated its 100th anniversary this year with a variety of events and festivals taking place all over the world. As part of the Group's concluding anniversary celebration on October 17, CEO Gerhard Federer, who has retired for health reasons, received a ceremonial farewell.

Gerhard Federer, who announced his resignation in April 2013, has worked as part of the board of management of the Schunk Group since 2003 and became the CEO in 2007. "It is extremely hard for me to leave Schunk, but dealing with significant health problems and leading a company with over 8,000 people just cannot be done together for a long period of time," stated Federer.

Dr Arno Roth, who has been a member of the management board since 2007, was announced as Federer's successor and began his position on November 1, 2013. "I am excited to take on the great challenge of leading such an internationally active corporation. It will be an exciting and fulfilling task to get involved in even more different markets and cultures," stated Dr Roth. Dr Roth will be the CEO for the Sinter Metals Division as well as being responsible for the areas of personnel, finances, strategy development, public relations work, and investment controlling on the corporate level.

From left to right: Dr Heinz-Joachim Mäurer, Dr Arno Roth, Peter Manolopoulos and Gerhard Federer

Peter Manolopoulos also started work on November 1 as Roth's successor and will be responsible for the divisions of the Weiss Group and Sonosystems. Since 2002 Manolopoulos has held several leadership positions with the GEA Group AG, his last position there being the CEO of GEA Energietechnik GmbH. In 2011 he switched to Roth & Rau AG to work as part of the board of management for operative business.

The three-person management board is completed by Dr Heinz-Joachim Mäurer, who will continue to be responsible for the Materials Division, which produces carbon, graphite, carbon fibre-reinforced carbon, silicon carbide, aluminium oxide and quartz.

www.schunk-group.com

BorgWarner sees strong profit performance on increased sales

BorgWarner Inc., a producer of automotive turbochargers and emission systems based in Auburn Hills, MI, USA, reported a 65% rise in quarterly profit with net income rising to $166.8 million in the third quarter ended September 30 compared with the same period in 2012. Sales revenue rose 7% to $1.81 billion from $1.70 billion in Q3 2012.

"Operational efficiency and cost controls enabled us to post a strong operating income margin of 12.5% in the quarter," stated CEO James Verrier. "The focus on fuel economy and improved emissions in the automotive sector continued to drive growth for BorgWarner."

Currently 50% of BorgWarner's sales come from Europe. The company's engine group, which supplies turbochargers, exhaust-gas recirculation coolers and variable-cam timing devices, accounting for two-thirds of sales, reported a 4% increase in sales to $1.2 billion.

The drivetrain group, which sells all-wheel-drive systems and transmission components, reported a 13% rise in sales to $604 million. Borg Warner is both a major user as well as producer of Power Metallurgy parts.

In July this year BorgWarner MorseTec closed its plant in Cortlandville, New York State, USA, which produced PM sprockets for engine timing systems and PM transfer cases.

www.borgwarner.com

Auto manufacturers present supplier awards to key PM parts makers

General Motors recently presented its 2013 Supplier Quality Excellence Award to a number of the company's key Powder Metallurgy component suppliers.

The award recognises GM suppliers who have demonstrated the highest levels of quality performance over the previous twelve months. Winning plants must meet a set of stringent quality and delivery performance grading criteria to be eligible for the award, which is only given to a select group of GM's top performing suppliers.

Awards from Ferrari and Hyundai have also been presented to PM component manufacturers, further recognising the value of Powder Metallurgy parts and the companies who manufacture them.

GKN Sinter Metals receives four GM Supplier Quality Excellence Awards

GM presented four Supplier Quality Excellence awards to GKN Sinter Metals plants in North America and Germany. The award winning plants in the US were identified as Germantown, Wisconsin, St. Mary's/Kersey, Pennsylvania and Conover, North Carolina. Bad Brückenau was named as the award winning plant in Germany. This is the second year in a row that GKN has received this award at multiple plants.

www.gknsintermetals.com

Cloyes Gear & Products receives GM Supplier Quality Excellence Award

Cloyes Gear & Products, a supplier of numerous sintered and machined engine components and timing kits to General Motors received a Supplier Quality Excellence Award for 2013.

Headquartered in Arkansas, USA, Cloyes has three manufacturing facilities and employs 900 people. The company has been a long time Tier 1 supplier, being a high volume manufacturer of automotive timing drive systems and related components.

www.cloyes.com

GM quality award for PMG Asturias

PMG Asturias Powder Metal SAU, Mieres, Spain, has also been awarded a General Motors Supplier Quality Excellence Award for 2013.

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

www.pmgsinter.com

Metaldyne receives awards from General Motors and Hyundai for quality excellence

Metaldyne, LLC headquartered in Plymouth. Mich., USA, has reported that three of its global operating plants have received customer awards for 2013, including two Supplier Quality Excellence Awards from GM and a supplier award from Hyundai.

GM recognised Metaldyne's PM facilities located in St. Marys, Pennsylvania, USA and North Vernon, Indiana, USA. Metaldyne's plant in Pyeongtaek, South Korea was also awarded with a certificate from Hyundai Mobis for 100% on-time delivery of balance shaft modules used in the engines of several top selling Hyundai and Kia vehicles.

www.metaldyne.com

Mahle receives supplier award from Ferrari

Italian supercar manufacturer Ferrari awarded Mahle with a "BEST GT Supplier Award," recognising the company for its long-standing support in the field of engines. The award was presented at the traditional Podio Ferrari event, organised by Ferrari in order to honour its suppliers and strategic partners for outstanding achievements in the past twelve months.

With its two business units Engine Systems and Components as well as Filtration and Engine Peripherals, Mahle ranks among the top three systems suppliers worldwide for piston systems, cylinder components, as well as valve train, air management, and liquid management systems.

www.mahle.com

Dynamet Technology receives ITA's 2013 Titanium Applications Development Award

Dynamet Technology, Inc., has announced that it has won the International Titanium Association's (ITA) 2013 Titanium Applications Development Award. The founder, President and Chief Executive Officer of Dynamet Technology, Inc., Stanley Abkowitz accepted the award at the Titanium 2013 conference in Las Vegas, USA.

Located in Burlington, MA, USA, Dynamet Technology has pioneered the development and application of titanium Powder Metallurgy (PM Ti) technology for some 40 years. Acceptance of PM Ti as a substitute for conventional Ti-6Al-4V mill products or forgings for use in aerospace components has been a long-sought objective that marks a breakthrough for the PM titanium industry, stated the company. Ti-6Al-4V is the most widely used titanium alloy for both aerospace and non-aerospace applications.

The annual ITA award recognises exceptional contributions to the advancement of technology and applications in the titanium industry. Brett Paddock, President of the ITA board, and the President and Chief Executive Officer of Titanium Industries Inc., Rockaway, NJ, USA, stated, "As a result of more than 40 years of sustained effort, Dynamet Technology, Inc. has achieved acceptance for use of the technology in commercial aircraft manufacturing. The ITA is pleased to honour this significant achievement, which promises to promote the use of titanium in many future applications through efficient production of near-net shapes using this innovative technology."

Dynamet Technology, Inc. recently garnered approval from Boeing Co., through Boeing Commercial Aircraft (BCA) after an extensive evaluation of Dynamet Technology's Ti-6Al-4V alloy product and development of a Boeing Materials Specification for powder metal titanium alloy manufactured by Dynamet Technology's PM Titanium processing approach. This effort resulted in Dynamet Technology, Inc. becoming the sole qualified supplier for Ti-6Al-4V powder metal products, meeting the requirements of the recently released Boeing Material Specification.

This qualification, along with Dynamet Technology's receiving AS9100C certification, includes all the requirements of ISO 9100:2008 plus further requirements relating to quality and safety. It was issued April 29 after successful completion of the quality-system audit performed by TUV Rheinland of North America Inc., Newtown, CT, an accredited third-party certification company. This qualification enables Dynamet Technology's titanium powder metal products to be used as an alternative to conventionally processed titanium for manufacture of commercial aircraft components.

"Dynamet's proprietary discovery of a more affordable and a faster-to-market titanium powder metal process enticed Boeing metallurgists and engineers to design qualifications around these results," stated Robert Hill, President of Solar Atmospheres of Western PA, USA, in his letter that nominated Dynamet Technology, Inc. for the application award.

Meeting the Boeing specification opens the door for the production of PM Ti-6Al-4V aircraft parts, from fuselage to landing-gear components, stated the company. The manufacturing technology offers the capability to create near-net-shape parts, which can reduce production costs and scrap rates as well as speed delivery. According to Abkowitz, this represents a significant business opportunity for the global titanium market.

The Dynamet Technology, Inc. EBS (Elemental Blend Sintering) process involves cold pressing, vacuum sintering plus an optional hot-isostatic pressing (HIP) step, all of which yields low-cost, high-density, preformed titanium alloy shapes. Abkowitz said there are two key breakthrough aspects in Dynamet Technology, Inc. process. First, the company's Powder Metallurgy process achieves tensile properties comparable to conventional wrought titanium products. Second, the process utilises special tooling technology, developed by Dynamet Technology, Inc., to produce near-net shapes.

Abkowitz added that the process also supports the development of novel alloys. Since part production involves sintering rather than melting, entire new titanium alloy families, incorporating the advantages of high-performance metals such as tungsten, zirconium, tantalum and niobium as alloying elements, can be created.

www.dynamettechnology.com

ASIMCO to further expand its PM capabilities with two joint ventures

ASIMCO Shuanghuan based in Chaoyang District, Beijing, China, and Nippon Piston Ring of Japan have announced the establishment of a new company, NPR ASIMCO Powder Metallurgical Manufacturing Co., Ltd, to be based in Yizheng, China.

The joint venture will produce a range of sintered automotive valve seats and other automotive Powder Metallurgy parts.

Earlier this year ASIMCO Shuanghuan announced a joint venture with ASM Alloy Materials (Yizheng) Co., Ltd. (ASIMCO ASM), located in Yizheng Auto Industrial Park, Jiangsu Province, China. ASM has advanced Powder Metallurgy capability primarily focused on demanding automotive component applications.

It was stated that the joint venture with ASM Alloy would help ASIMCO Shuanghuan expand its range of capabilities in the automotive valve train arena beyond that of piston rings and camshafts, allowing the ASIMCO Group to penetrate both the Chinese and global Powder Metallurgy markets.

ASIMCO Technologies Ltd was founded in 1994 and has current annual sales of over US$500 million, making it one of the largest independent components manufacturers in China.

www.asimco.com

Expansion of mould making facility in Taiwan to meet growing international demand

Hua Cheng Moulding Co., Ltd, a manufacturer of precision moulds for the Powder Metallurgy, Ceramic and Metal Injection Moulding industries has announced the opening of a new production facility in Miaoli County, Taiwan. The new site will employ around 100 people and focus on the manufacture of high precision moulds for various PM, MIM and CIM applications.

In addition to the new production facility, Hua Cheng Moulding has invested in new high precision CNC machines from leading European manufacturers to duplicate the production capacity and technology of the company's Changshu facility. The investment includes Agie Charmilles EDM & WEDM, Carl Zeiss CMM, Makino Milling and Mikron High-Speed Milling.

Hua Cheng Moulding Co., Ltd was established in 1978 and offers a range of mould manufacturing options to both Asian and international customers. The company can produce moulds to ISO 9001 certification. Tools are made from Crucible, Böhler or Uddeholm steels or tungsten carbide with local equivalent steels and carbides also available if required.

David Lemon, Hua Cheng Moulding's European agent told *Powder Metallurgy Review*, "Hua Cheng can offer a cost effective alternative for the production of advanced moulds for PM, MIM and CIM applications. As well as providing a competitive lead-time, their experienced and knowledgeable engineers can help optimise mould design and extend tool life through material selection and 'design for manufacture' principles."

As well as supplying Taiwan's leading PM company, Porite Taiwan Co., Ltd, Hua Cheng is actively promoting itself to markets in Europe, USA and Asia. "The new facility is in response to growing domestic and international demand. Our philosophy is to focus on providing economic, high precision products with short lead-times" stated Lo Yuan Feng, President of Hua Cheng Moulding (Changshu & Taiwan) Co., Ltd.

www.moldmaker.com.tw

Hua Cheng Moulding's new facility in Taiwan

Award winning PM parts announced by Taiwan Powder Metallurgy Association

The Taiwan Powder Metallurgy Association (TPMA) has announced winners of its "Innovation Awards" during the association's annual conference in August 2013.

The first innovation prize was awarded to China Steel Co. for its new Si-Al sputtering target. To resolve the problems of grain coarsening, composition segregation, and low density in cast and spray formed Si-Al targets, gas atomised Si-Al powder was consolidated using HIP below the eutectic temperature of Si-Al. Fully dense targets with minimised segregation and fine grains have been produced, as shown in Fig. 1, for the use of IGZO (Indium-Gallium-Zinc-Oxide) flat panels.

The second innovation winner was Taiwan Porite for its development of a set of PM parts, cover plate and hub clutch, used in the transmission gear box of a 6-speed front wheel drive automobile (Fig. 2). The cover plate was made of Sint-D39, pressed to 7.0 g/cm^3 with a 500-ton CNC press. The hub clutch was made of the same material and green density and was pressed using a 750 ton press. This gear set replaces machined wrought counterparts with a cost saving of $16/set. The annual production quantity is around 160,000 sets.

The third innovation winner was MIM parts producer Taiwan Powder Technologies (TPT) for its new High Performance High Density PM (HPM) process. Using fine ferrous powders and a pre-treatment process, conventional press and sinter process is applied to the powder to produce PM parts with MIM properties. The Fe-Ni-Cr-Mo products presented have a sintered density of 7.6g/cm^3, tensile strength of 1,800 MPa, hardness of 50HRC, elongation of 5%, and impact energy of 60J. Age hardened 17-4PH HPM parts with a density of 7.6g/cm^3 were also presented, which are rarely seen in the PM industry. Structural parts used in hand tools and gear sets have been in production at TPT since early 2013, as shown in Fig. 3. These parts had been produced using the MIM process and now replaced by HPM due to the cost saving of about 35% and better dimensional control due to less shrinkage during sintering.

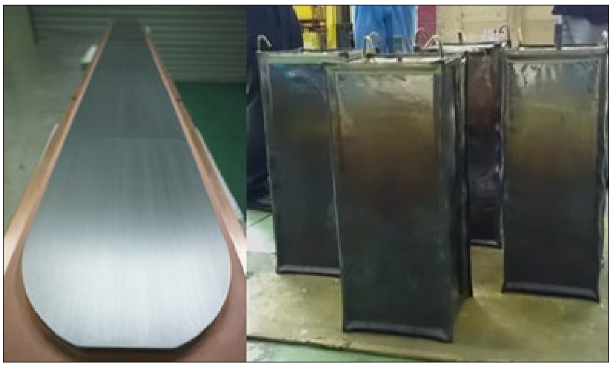


Fig. 1 A HIPed Si-Al sputtering target (2300mm x 200mm x 10mm) for the 6th generation of flat panels (left); As-HIPed encapsulated cans (right)

Fig. 2. Cover plate (left) and hub clutch (right) used in the gear box of a front-wheel-drive 6-speed automobile

Fig. 3 A new HPM process is applied by TPT to produce PM parts with MIM properties

Sumitomo starts tungsten refining and scrap recycling operations in the US

Sumitomo Electric Industries, Ltd. (SEI) has announced the start of tungsten refining and scrap recycling operations in the United States. Sumitomo Electric Carbide, Inc., a 100% subsidiary of Sumitomo Electric, and New York Tungsten L.L.C., a subsidiary of Buffalo Tungsten Inc., a tungsten powder producer in the United States, have established a joint venture company, Niagara Refining LLC (NIRE), to produce tungsten trioxide (WO_3) from raw ore as well as recycled material. Operations are set to begin in March 2014.

Tungsten is the primary raw material in carbide cutting tools and is found in only a limited number of countries, therefore its supply can be highly volatile.

Until now, A.L.M.T Corp., a subsidiary of Sumitomo Electric, has been importing WO3 from China and other countries to produce tungsten carbide powder as a raw material for carbide tools. A.L.M.T has also been engaged in tungsten scrap recycling at its Toyama plant since 2011. With the start of NIRE's operations, Sumitomo Electric will be able to produce raw materials for tungsten using both methods: refining tungsten ore from tungsten mines and recycling scrap collected from the market.

Sumitomo Electric will accelerate its activities to facilitate a stable supply of tungsten raw materials, utilising WO_3 production by NIRE and tungsten carbide powder production by A.L.M.T. This will allow Sumitomo Electric to control the supply chain from raw materials all the way to the finished product, which will further strengthen its competitiveness, stated the company.

www.global-sei.com

Swastik Tungsten Pvt Ltd increases manufacturing capacity of tungsten powder

Swastik Tungsten Pvt Ltd has recently increased its manufacturing capacity for tungsten metal powder at its facility in Shrirampur, Maharashtra, India, some 130 km from Mumbai. The company states that it has installed a modern state of the art tungsten metal powder manufacturing unit at the site, with a monthly capacity of 22 mt.

Swastik Tungsten was established in 2000 and supplies tungsten metal powder and other non-ferrous metal powders to the domestic and international markets.

"We have a team of advanced professionals who are committed towards bringing innovation in terms of the features of the products. Our professionals adopt a committed approach towards excellence," states the company.

"We are equipped with advanced testing equipment to ensure that the products are properly checked for specific qualities. We have our own laboratory to test the products and ensure that the clients get the best."

Swastik Tungsten Pvt Ltd, located in Shrirampur, Maharashtra, India, has increased production of tungsten metal powder

Swastik Tungsten's Managing Director, Ajit Arbatti, also announced plans to set up a sintered carbide MIM plant to further diversify the company's activities.

www.swastiktungsten.com

Call for Papers issued for Euro PM2014 conference

The Euro PM2014 International Conference and Exhibition will be held in Salzburg, Austria, September 21 – 24 2014. Organised by the European Powder Metallurgy Association (EPMA), the event will host a programme of over 250 oral and poster papers that will cover all aspects of Powder Metallurgy, including:

- Additive Manufacturing
- Hard Materials & Diamond Tools
- Hot Isostatic Pressing
- New Materials and Applications
- PM Structural Parts
- Powder Injection Moulding

A Call for Papers has been issued, with the organisers requesting that abstracts are submitted on-line no later than February 5, 2014. In addition to the main technical programme there will also be a number of special interest seminars, EPMA working group meetings and workshops.

www.epma.com

Höganäs PoP Day 2013: Future challenges and opportunities for the Powder Metallurgy industry explored

Around 200 participants from the world of Powder Metallurgy, as well as key guests from the automotive industry, gathered in Höganäs, Sweden, on September 18 to take part in Höganäs AB's PoP Day 2013. A comprehensive all-day programme included presentations, technical demonstrations, tours and discussions as well as a lively social programme.

Alrik Danielson, CEO of Höganäs, welcomed participants stating, "Our common goal is to expand the market for metal powder technology by finding new applications through improved performance and technological advancement. Through close cooperation and partnerships, thorough understanding of application requirements and design aspects, and by adding process development and powder material innovations to the equation."

"I know that we can create wonders together. Everyone involved has acquired a lot of experience during the PoP Centre's four years of operation. Together with the recent technology investments made, we are in a unique position to push for even higher growth to the benefit of everyone involved. That is the whole purpose of this initiative."

A global perspective on the development of PM automotive gears

The PoP Day 2013 commenced with six presentations by leading figures in the automotive and PM business. Speakers included representatives from Mazda, Getrag International GmbH, Miba Sinter and PMG USA as well as Höganäs itself and the main focus was on using PM technology to produce car transmission gears. The message was clear that the potential is huge, but several challenges have to be overcome.

In the presentation "System integration with PM: Gear system design using powder metal" Anders Flodin, Höganäs AB, and Peter Karlsson, Vicura, gave a detailed overview of the advantages of PM gears as well as the development challenges. "Transmission gear system design requires full control of both design and manufacturing in order to accommodate the full potential of gear optimisation," stated Flodin. The importance of being able to predict transmission system behaviour and having access to statistically correct material data was also emphasised.

"By utilising powder metal's lower Young's modulus, gear geometry can be optimised to theoretically improve the performance compared to conventional steel designs." The opportunity to reduce number of parts and production steps, the possibility to decrease transmission error as well as future possibilities to further improve transmission efficiency and gear manufacturing processes were also presented.

One participant commenting on the presentations stated, "A highlight for me was to hear that Getrag, the world's largest independent gearbox manufacturer, will start industrialising their PM gear manufacturing. That's a fantastic sign that the PM industry is on the right track. If they start doing it, others will follow."

Following the technical presentations, visitors witnessed the unveiling of the company's "Soon Powered by Powder Metal Transmission Gears" medium sized estate/station wagon car. This development, in cooperation with some of the leading companies in the entire PM value chain, is set to be a major breakthrough with one enthusiastic visitor commenting, "We could never imagine that all the gearbox gears could be made from powder metal. This is the future of PM manufacturing."

Dr. Anders Flodin and gearbox cut-away model

Alrik Danielson, CEO of Höganäs, welcomed participants to the 2013 PoP day

Hans Söderhjelm, Vice President, Marketing & Product Development, speaking at the 2013 PoP day

Toro Ogasawara, from Mazda Motor Corporation's Powertrain Development Division, speaking at the 2013 PoP day

A PoP Centre tour was a part of the all-day programme

Advanced production technologies on display in the PoP centre

Many of the technical innovations that have enabled Höganäs and its partners to progress PM gear technology to its current level were on display on an 11-stop tour of the PoP Centre. Each of the 11-stops featured presentations by experts in the relevant technology. The stops included helical gear compaction, novel sinter and low pressure carburising technology, PM gears, FZG gear testing, machinability and prototyping, Metal Injection Moulding (MIM), Additive Manufacturing (AM) and others.

"As a PM producer I was impressed by the new equipment and capabilities, but also by the 3D printing," said one visitor. "The ways Höganäs finds to increase the PM business is fantastic."

Hans Söderhjelm, Vice President, Marketing & Product Development, concluded, "The 'Power of Powder' campaign has been running for four years. We wanted to show customers and end-users what we can actually achieve at our PoP Centre when working closely together, and hopefully they will get inspired to collaborate with us on future projects and to jointly develop new business opportunities."

During the PoP Day Höganäs also presented its latest video promoting the current and future use of metal powders, PM's environmental credentials and the opportunities for PM in gear applications.

www.hoganas.com

EPMA distinguished service and keynote paper awards presented in Gothenburg

Gothenburg, Sweden's second city and an important centre for trade and manufacturing, played host to this year's Euro PM Congress and Exhibition which was organised and sponsored by the European Powder Metallurgy Association (EPMA). The EPMA stated that the event, which took place from September 15-18, attracted a strong attendance of over 700 participants, including delegates from nearly fifty countries in all regions including the Far East, Africa and the Americas.

The event also included an important trade exhibition with 85 stands covering companies from all parts of the PM supply chain. Jonathan Wroe, EPMA Executive Director stated, "Gothenburg has proved an excellent location for an event with its scope expanded to include Additive Manufacturing. We would like to thank the City of Gothenburg, our members and delegates for their support, which is much appreciated".

A full social programme included a welcome reception, a lively exhibition reception sponsored by *Powder Metallurgy Review* magazine and a traditional Gala Dinner. This was held at the historic Valand centre in the heart of the city and provided a suitable finale to a dynamic and productive event.

A new innovation for EuroPM conferences was the awarding of four special keynote paper awards to those papers selected as having the highest merit. The winners were Helen Dugdale from Rolls Royce plc., Dipl. Engineer Markus Hadyn from Plansee SE, Dr Inigo Iturriza from CEIT and Per Lindskog, PM Consultant from Sweden.

EPMA Distinguished Service Award winners recognised

Some 500 people at the plenary session of Euro PM2013 saw EPMA President Philippe Gundermann present the association's Distinguished Service Awards to Dr Bryan Roebuck from the National Physical Laboratory London, Prof Jose Torralba from the University Carlos III Madrid and John Dunkley from Atomising Systems Ltd.

Dr Bryan Roebuck

Dr Bryan Roebuck obtained his degrees in metallurgy at Manchester Institute of Science and Technology and has worked at the NPL since 1970 where he has built up a reputation as leading expert in the measurement science underpinning the characterisation and mechanical properties of hard metals. He is now an Emeritus Research Senior Fellow in Characterisation and is a member of several international committees relating to hard materials.

Prof Jose Manual Torralba

Prof Jose Manuel Torralba studied as a Mechanical Engineer at the Technical University in Madrid and spent ten years working as an armament and material engineer before becoming head of the PM research group at UC3M in 1996.

He has since become a Vice Rector of UC3M and Deputy Director of IMDEA a technology centre based at the university. He has published more than 400 scientific papers and also supervised 19 Phd theses.

Dr John Dunkley

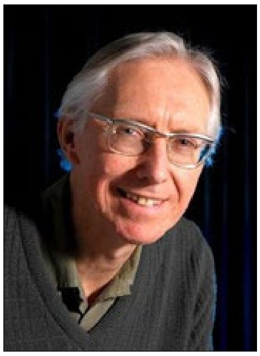
Dr John Dunkley studied chemical engineering at Cambridge University before joining Davey Ashmore Ltd to work on continuous casting. In 1972 he attended his first PM event and subsequently became the manager of the companies PM division selling atomisers.

In 1992 after the closure of the company he established his own operation called Atomising Systems Ltd which has grown over the years to employ more than 50 staff in a 3000m^2 facility. He has also been chairman of the IoM3 Particulate Engineering Committee and editor of the journal *Powder Metallurgy*.

www.epma.com

Keynote Paper Award winners were recognised during the opening session

The Mayor of Gothenburg welcomed delegates to the Exhibition Reception sponsored by Powder Metallurgy Review magazine



Dr Bryan Roebuck

Prof Jose Manual Torralba

Dr John Dunkley

New production process offers greater opportunities for metallic nanoparticles

The VTT Technical Research Centre of Finland is developing new techniques for the production of metallic nanoparticles. In a statement issued by the centre it is claimed that their new production reactor, operating at atmospheric pressure, reduces the production costs of multicomponent particles, enabling the production of metallic nanomaterials which are not yet commercially available for research and product development needs.

The most significant applications for metallic nanoparticles currently have to do with the utilisation of their optical and magnetic properties, conductive inks and catalysts. These are also the primary areas of focus in the related development work. In the future, state VVT, optically transparent coatings will make it possible to replace precious metals with copper in applications such as solar cells, opto-electronics, and diagnostics.

In the manufacturing of conductive inks the major focus of interest is the replacement of silver with copper, which is significantly cheaper. In this field the small size of the particles affects, for example, their sintering properties, stability of the inks, and printability.

The magnetic properties of metallic nanoparticles are considerably stronger than those of oxides, which are currently being used in the industry. In addition, the use of alloy metals makes it possible to customise particle properties to meet the needs of each application. Potential applications include data storage, magnetic polymer composites, sensor and machine actuators and, in the long term, even the treatment of illnesses.

Since VTT's new reactor operates at atmospheric pressure its construction and usage costs are low. The process is continuous and allows for affordable source materials to be used, states the research centre. The wastage rate is low, while the produced powders are pure. The reactor is particularly well suited for the production of alloy metal nanoparticles. The particle coating protects the particles from aging during handling and storage, also making it possible to combine organic compounds with metallic particles.

VTT's new reactor operates at atmospheric pressure

Ari Auvinen, Principal Scientist at VTT, stated that the next nano-innovations from Finland will be related to conductive inks, magnetic polymers, and catalysts. Commercial production of particles also creates interesting business opportunities. "3D printing is currently in increasing demand, and in the coming years, the demand for metallic materials suitable for use with printers is also likely to arise," stated Auvinen.

www.vtt.fi

EOS expands metal powder options with NickelAlloy HX

Additive manufacturing system provider EOS has expanded its metals range of with the introduction of the EOS NickelAlloy HX. The heat and corrosion resistant nickel-chrome-iron-molybdenum alloy has high strength and resistance to oxidisation, even at elevated temperatures up to 1200°C.

The material is optimised for use in the company's EOSINT M 280 system and is typically processed with a layer thickness of 20 µm. Application areas include aerospace, heating elements in conveyor ovens, and industrial blast furnaces.

Andreas Graichen, Product Developer (Gas Turbines) at Siemens Energy stated, "We use EOS' additive manufacturing process for constructing prototypes, rapid manufacturing and rapid repair. Thanks to this technology, we are able to cut repair times and reduce costs for customers that commission us to repair industrial gas turbines."

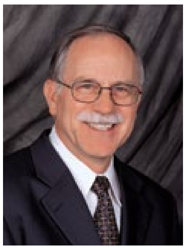
The material's properties make it ideally suited to repair, as it is able to withstand the high temperatures to which gas turbines are constantly exposed. "For gas turbine burner repair, for example, instead of cutting away and discarding a large part of the burner head, we leave the structure intact, remove the top 20 mm or so, and then simply print a new combustion head. The process delivers significant savings both in terms of repair times and costs," added Graichen.

Adapter for use in chemical industry made from EOS NickelAlloy HX

Parts built from EOS NickelAlloy HX can be subsequently heat-treated to modify the characteristics of the material. Whether hardened or as originally built, parts can be finished as required and surplus unexposed material can be re used.

www.eos.info

Chuck Hull receives Stibitz award for inventing Stereolithography



Chuck Hull, inventor of the Stereolithography process

Chuck Hull, the inventor of Stereolithography and founder of 3D Systems, was honoured with the George R Stibitz Computer and Communications Award by Montana State University on October 3, 2013, in Bozeman, MT, USA.

Hull invented the original 3D printing technology, Stereolithography (SLA), and led the development of the .stl file format, which continues to be the standard in ultra high-definition 3D printing and CAD connectivity. Hull set to develop additive layer manufacturing (AM) to help an ailing automotive industry regain competitive advantage. After years of failed attempts Hull's perseverance and inventiveness paid off when he successfully printed a teacup on March 9, 1983, and went on to file a patent for what he called Stereolithography and found 3D Systems in 1986.

Hull continues to be at the forefront of AM technology as 3D Systems' Chief Technology Officer, celebrating 30 years of continuous 3D printing innovation and presiding over seven different 3D print technologies, over 100 materials and 1,200 patents.

The award program was established in 1997 by George Keremedjiev, founder and director of the American Computer and Robotics Museum in Bozeman, MT. Hull is being honoured alongside the late Walt Disney and John Holland, an expert in complex adaptive systems. MSU will also be honouring primatologist Frans de Waal and 3M executive Jean B Sweeney with the Edward O Wilson Biodiversity Technology Pioneer Award.

"Seemingly a week cannot pass by without the mention of 3D printing for advanced manufacturing in both the general and technical media," Keremedjiev said. "It is, bar none, the 'hottest' technology for modern and future manufacturing in the world. In fact, much of President Obama's and the Congress' manufacturing initiatives center themselves around the proliferation of Mr Hull's invention (3D printing)."

"I am deeply honoured to receive the distinguished Stibitz Award alongside innovators who have changed the world and improved the human condition in unimagined and powerful ways," stated Hull.

www.3DSystems.com

ExOne begins $20 million expansion

The ExOne Company, a manufacturer of 3D printing machines and printed products, has held a ground breaking ceremony for the construction of a new $20 million facility in Gersthofen, Augsburg, Germany. The facility will include space for production, warehouse, service and R&D, as well as housing ExOne's European headquarters. Construction is scheduled for completion in the latter half of 2014.

The new facility will allow ExOne to consolidate its five existing leased facilities in Augsburg into the new site, as well as providing expansion capacity.

During the ceremony Rainer Hoechsmann, General Manager of ExOne GmbH, highlighted the company's continued commitment to the region. "This event marked a significant step forward as we capitalise on the substantial business foundation we have created in Augsburg to access global markets," stated Hoechsmann.

ExOne builds 3D printing machines at its factories in the United States and Germany. The company also supplies the associated materials, including consumables and replacement parts, along with other services including training and technical support for purchasers of its machines.

www.exone.com

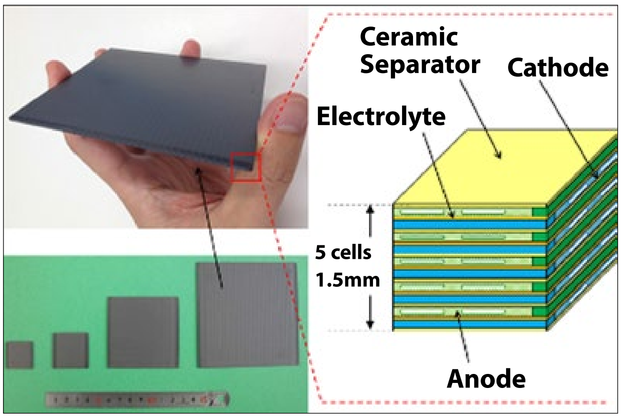
FCO Power develops high volumetric power density, low-cost SOFC stack

FCO Power Inc., based at the University of Tokyo, Japan, has announced the development of a next-generation solid oxide fuel cell (SOFC) which achieves high volumetric power density, 3 kW/L, at low cost. The Printed Fuel Cell™ is a SOFC stack in which all single cell layers, including separators (anode, electrolyte, cathode and ceramic separator) are laminated repeatedly before sintering and subsequently simultaneously sintered only once as a stack.

FCO Power states that the fuel cell does not require a cell support because it does not need to maintain mechanical strength as single cell unit. As a result, the total thickness of a single cell and separator is just 0.3 mm, which is approximately one tenth the thickness of conventional technology.

Because it is so thin the Printed Fuel Cell™ achieves 3 kW/L, a figure that is claimed to be the highest level yet attained. This significantly surpasses the New Energy and Industrial Technology Development Organization's (NEDO) stack power density target for 2020 to 2030, which is 0.4 to 1 kW/L.

Additionally, the Printed Fuel Cell™ has a simple, thin laminated structure that requires a limited amount of material and parts, making it suitable for low-cost, automated mass production. As a result, FCO Power expects to be able to price the Printed Fuel Cell™ at a level that is well below NEDO's target stack price of JPY 50,000 /kW for 2020 to 2030.



According to FCO Power, the Printed Fuel Cell™ achieves the highest level of volumetric power density in the world

Among the several types of fuel cell available, SOFCs are expected to become especially widely used because of their higher power generation efficiency and ability to operate with a diverse variety of gases, including renewable biogas. However, reducing the cost of fuel cells, especially SOFC stacks, is a major issue for broad application.

FCO Power aims to commercialise the Printed Fuel Cell™ around 2018 to 2020 with a focus on application in limited spaces, such as in apartments for home use, and for distributed power use in offices and factories, which require significant cost efficiency.

www.ecobyfco.com

New Additive Manufacturing conference to run alongside PM2014 World Congress, Florida

The Metal Powder Industries Federation (MPIF) has announced its inaugural conference on "Additive Manufacturing with Powder Metallurgy" (AMPM) will take place May 18 - 20 2014, in Orlando, Florida, USA.

This new conference will run alongside the PM2014 World Congress on Powder Metallurgy & Particulate Materials and the Tungsten, Refractory & Hardmaterials Conference, taking place at the same venue.

Co-chairmen Gregory Morris, GE Aviation, and Joseph Strauss, HJE Company, Inc., anticipate that presentations will include the perspective of metal powder producers, toll providers and end-users of AM processes, R&D programs from academia and consortiums, and equipment manufacturers. Expected topics will include materials, applications, technical barriers, process economics, and new developments.

www.mpif.org

Öhlins Racing and Exmet look to 3D printing of components from amorphous alloy powders

Sweden's Exmet AB and Öhlins Racing AB have signed a license agreement for the use of Exmet's 3D printing technology to produce amorphous alloy components. Öhlins Racing develops and manufactures a range of components primarily for the motor-sport and aftermarket segment, and it is hoped the use of amorphous alloys will lead to increased performance in a number of applications.

Amorphous alloys (also known as bulk metallic glasses) lack crystalline microstructure and have a number of unique properties. Iron-based amorphous alloys, ie. amorphous steels, have twice the strength and ten times the elasticity compared to high-quality steel alloys and four times the strength of titanium alloys. Amorphous alloys are also chemically resistant, i.e. they are stainless.

"We are very pleased that our strategy to target leading high-end technology companies now has begun to pay off", stated Mattias Unosson, CEO of Exmet AB. "The agreement with Öhlins Racing will accelerate the technical development and commercialisation of our technology."

"This exciting materials technology from Exmet will allow our customers within motorsport to further sharpen their competitive edge", added Lars Macklin, Vice President Conventional Systems at Öhlins Racing. "History shows that the success of Öhlins Racing is built on early adoption and application of new technologies, so this agreement is in line with our proven successful strategy."

Exmet has managed to manufacture amorphous net shape components by metal powder bed additive manufacturing using either laser or electron beam based systems. The company state that their technology will increase the potential market for amorphous metals by removing some of the obstacles connected to the more traditional manufacturing methods of amorphous metal components.

www.exmet.se

A sample of Additive Manufactured amorphous alloy from Exmet using EBM (Electron Beam Melting), measuring 50x50x5mm. Samples with thickness of 20mm have been successfully manufactured using DMLS (Direct Metal Laser Sintering)

Titanium Powder Metallurgy: Developments and opportunities in a sector poised for growth

Powder Metallurgy is an attractive approach for the cost effective production of high integrity titanium components that deliver improved performance in aerospace and other applications where superior mechanical properties and excellent corrosion resistance are an advantage. In this comprehensive review Dr F H (Sam) Froes discusses various aspects of titanium PM, from powder production to consolidation methods that include the Blended Elemental approach, Pre-Alloyed techniques, Additive Manufacturing and Spray Deposition. Information on recent technical developments and market size is included, as well as predictions on future industry growth.

Titanium alloys are amongst the most important of the advanced materials which are key to improved performance in aerospace and terrestrial systems [1-16]. This is because of the excellent combinations of specific mechanical properties (properties normalised by density) and outstanding corrosion behaviour exhibited by titanium alloys. However, negating widespread use is the high cost of titanium alloys compared to competing materials. This has led to numerous investigations of various potentially lower cost processes [3-6], including Powder Metallurgy (PM) techniques [1,2,15,16].

In this article the titanium PM scenario will be reviewed, dividing the various technologies into the categories shown in Table 1. Basically the Powder Metallurgy techniques to be discussed are the Blended Elemental (BE) approach, Pre-Alloyed (PA) methods, Additive Manufacturing (AM), and Spray Deposition (SD). Techniques such as Metal Injection Moulding have been widely covered in *Powder Injection Moulding International* and Far from Equilibrium processing methods (Rapid Solidification, Mechanical Alloying and Vapour Deposition) are discussed elsewhere [1].

In publications over the past few years [3-6] the cost of fabricating various titanium precursors and mill products has been discussed and it has been pointed out that the cost of extraction is a small fraction of the total cost of a component fabricated by the cast and wrought (ingot metallurgy) approach. To reach a final component the mill products must be machined, often with very high buy-to-fly ratios which can reach as high as 40:1. The generally accepted cost of machining a component is that it doubles the cost of the component (with the buy-to-fly ratio being another multiplier in cost per pound). This means that anything that can be done to produce a component which is closer to the final configuration will result in a cost reduction, hence the attraction of near net shape PM components [1-6,15,16].

Category	Features	Status
Additive Manufacturing	Powder feed melted with a laser or other heat source	Pilot production
Powder Injection Moulding	Use of a binder to produce complex small parts	Production
Spraying	Solid or potentially liquid	Research base
Near Net Shapes	Prealloyed and blended elemental	Commercial

Table 1 Categories of titanium Powder Metallurgy

Type / Process	Elemental or Pre-alloyed	Advantages	Status/Disadvantages
Hunter Process (pure sodium)	Elemental	Low cost, excellent for cold press and sinter	Limited availability, high chloride
HDH* Kroll Process (pure magnesium)	Elemental	Lower cost, good compactibility, readily available, low chloride	
HDH powder produced from alloys	Prealloyed	Readily available	High cost, fair compactibility
Atomised	Prealloyed	High purity, available	High cost, not cold compactable
REP/PREP **	Prealloyed	High purity	High cost, not cold compactable
Armstrong / International Titanium (ITP) Powder	Both	Compactable, moderate cost	Processibility/quality, production scale-up
Fray	Both	TBD	Developmental
MER ***	Both	TBD	Developmental
CSIRO TiRO ****	Both	TBD	Developmental
ADMA Products Hydrided Powder	Both	Lower cost and better compactability	Semi-commercial
CHINUKA #	Alloy possible but difficult	Can use impure ores	Developmental
CSIR ##	May be possible	Moderate cost	Developmental

Hydride-Dehydride, **Rotating Electrode Powder/Plasma Rotating Electrode Powder, ***MER Corp., Tucson, AZ, ** CSIRO Melbourne, Australia, # Cambridge , UK, ## Pretoria , South Africa*

Table 2 The characteristics of different types of titanium powders (modified from Abkowitz et al [18])

Production of titanium powders

The characteristics of the leading different types of titanium powders, that are either available or under development today, are shown in Table 2. This table is based in part on a recent review of powder production methods coauthored by McCracken [17]. The oxygen level of the Hydride-Dehydride (HDH) powder can be reduced by deoxidising with calcium. The spherical powders are generally used in conjunction with the Hot Isostatic Pressing (HIP) technique, where precision shape making requires high packing density, while the irregular shaped powders are used with cold compaction methods where good bonding between adjacent particles is required, for example good green density before high temperature sintering / HIP [1, 2, 15, 16]. It is possible to convert the angular HDH to a spherical morphology using the Tekna plasma spheroidisation process [17].

The development of new titanium production methods such as the ITP / Armstrong, FFC Cambridge, CSIRO, Chinuka, CSIR, MER and ADMA Products hydride processes shown in the table are aimed at lowering the cost of PM titanium powder. However, these powders are not yet available commercially and their relative cost and processing characteristics are yet to be established.

Pre-alloyed spherical powder

There are a number of companies/ processes which produce pre-alloyed spherical titanium powder including the following:

ATI Powder Metals (formerly Crucible Research Center)
Spherical gas atomised alloy powder, 100 pounds capacity melting furnace. 50 pounds of -100/+325 (-150/+45 microns) Ti-6Al-4V for $130.00 per pound

Advanced Specialty Metals (now part of Timet)
Spherical plasma rotating electrode process (PREP) -100/+325 (-150/+45 microns) Ti-6Al-4V for $189.00 per pound

Raymor (now includes Pyrogenesis)
Spherical plasma atomised Ti-6Al-4V powder. -450 to +60 mesh (-30/+250 microns) powder available. Regular grade (0.20 O_2 max) Ti-6Al-4V $41 per pound, low oxygen (0.13 max) $62 per pound [19]

Baoji Orchid Titanium
Spherical PREP. Ti-6Al-4V -70/+325 (-210/+45 microns), 0.13 oxygen max. $84 per pound

ALD Vacuum Technologies
Spherical gas atomised Ti-6Al-4V electrode induction melting gas atomisation

Sumitomo Sitex
Gas atomised (Ti-6Al-4V, oxygen 0.08-0.13 wt %

TLS Technik
Gas atomised Ti-6Al-4V with 0.13 oxygen. Ti-6Al-4V 100-270 mesh (53–150 microns), O_2 0.13 wt %, $73 per pound

Affinity International
GA and PREP. Preference to supply PREP at $40 per pound (2,000 kg quantity, -80 mesh regular grade 5, Ti-6Al-4V), $54 per pound (for 100 kg quantity)

Iowa State University / Ames Lab
Experimental gas atomisation, cost effective very fine spherical powder produced using a close - coupled high pressure supersonic gas (less than 325 mesh [45 microns]). Iowa Powder Atomization Technologies (IPAT) is currently in the process of

commercialising the process. IPAT will utilise this economically viable method to produce powders with a tenfold increase in the yields of fine powder suitable for Ti-MIM compared to other atomisation routes. The powders produced will also be suitable for use for the pre-alloyed/HIP approach to near net shape making

Tekna Plasma Systems Inc
Tekna's induction plasma spheroidisation process converts irregular shaped titanium powders to a spherical morphology. Typically an irregular powder of -100/+400 mesh (-150/+37) is converted to a spherical powder of the same size range (but with a significant improvement in tap density and flow rate)

Quad Cities Manufacturing Laboratory
To establish capabilities for PREP, GA, HDH and the Tekna induction plasma spheroidisation process (to convert HDH powders).

The atomised powders are generally pre-alloyed and spherical (Fig. 1a). Sponge fines, a by-product of sponge production, are angular. They are sponge-like in nature and

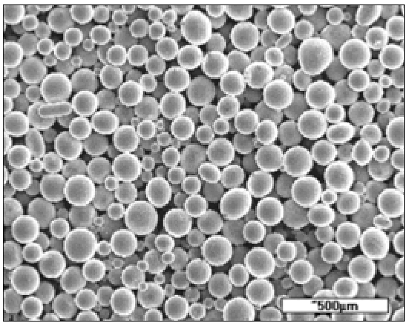


Fig. 1a SEM photomicrograph of a gas atomised pre-alloyed spherical Ti-6Al-4V (Courtesy of Affinity International)

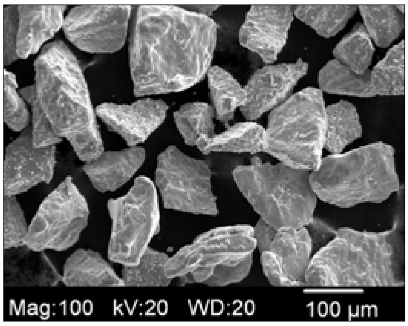


Fig. 1b SEM photomicrograph of sponge fines produced by the Kroll process (Courtesy Ametek)

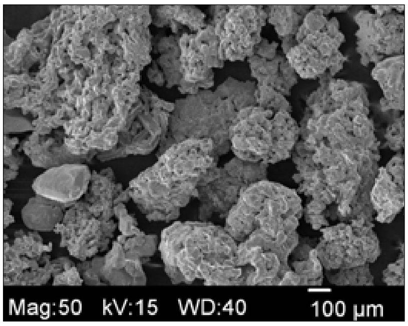


Fig. 1c SEM photomicrograph of angular HDH titanium powder (Courtesy Ametek)

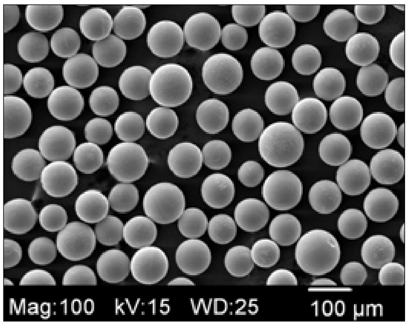


Fig. 1d SEM photomicrograph of spherical powder produced by processing angular HDH titanium to a spherical morphology using the Tekna technique

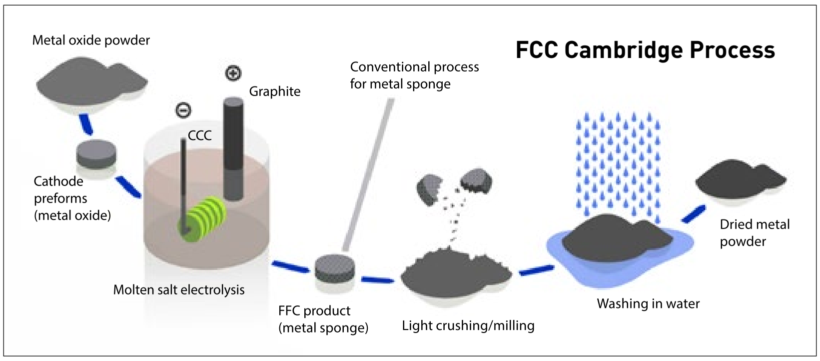


Fig. 2 Schematic of the FCC Cambridge Process (Courtesy Metalysis)

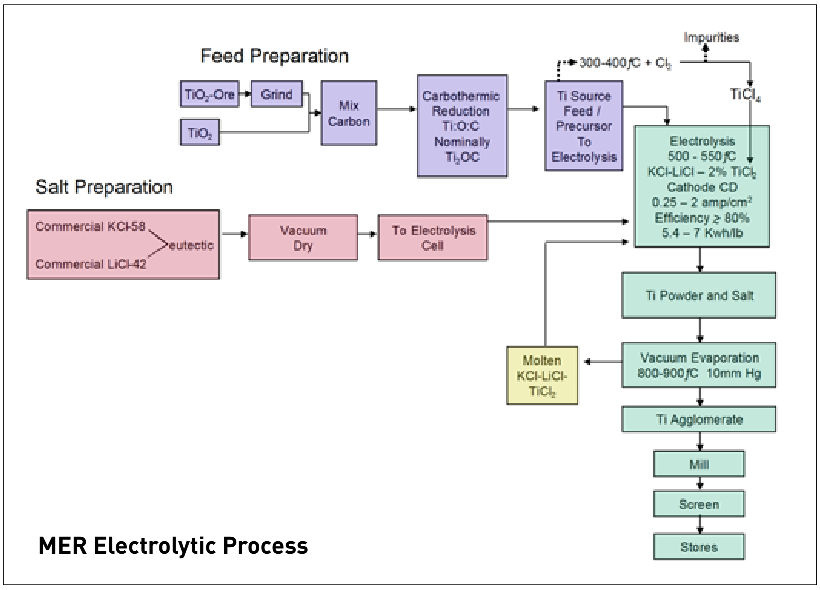


Fig. 3 MER overall process to produce titanium from a TiO_2 source (Courtesy Jim Withers)

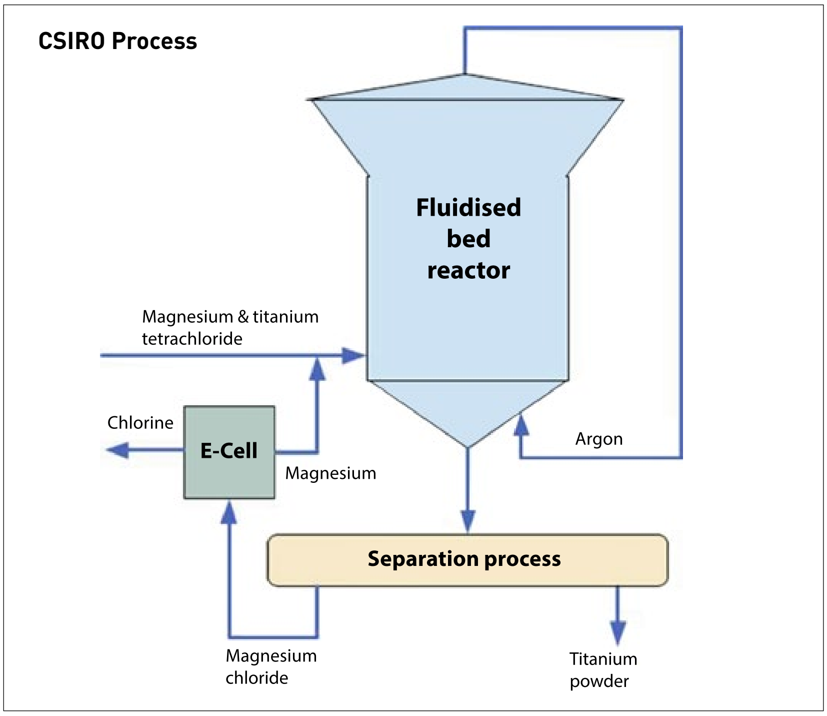


Fig. 4 Schematic of the CSIRO process for producing commercially pure titanium powder (Courtesy John Barnes)

contain remnant salt, which prevents achievement of full density and adversely affects weldability (Fig. 1b). Hydride-dehydride powders, which are generally also pre-alloyed, are angular in nature, (Fig. 1c) [17]. Conversion to a spherical morphology using the Tekna process is shown in Fig. 1d [17].

Non-melt angular powders

Six non-melt processes for the production of angular powder appear to have the greatest potential for scale-up [20-25], along with the additional hydride powder process which has been developed by Advance Materials Products (ADMA) [26] also of potential commercial interest. These six processes are the FFC Cambridge approach [20], the MER technique [21], the Commonwealth Scientific and Industrial Research Organization (CSIRO) methods [22], the Chinuka process [23], the CSIR approach [24], and the ITP/Armstrong process [25].

FFC Cambridge

In the FFC Cambridge approach titanium metal is produced at the cathode in an electrolyte (generally $CaCl_2$) by the removal of oxygen from the cathode, as shown in Fig. 2 [20]. This technique allows the direct production of alloys such as Ti-6Al-4V at a cost which could be less than product of the conventional Kroll process [1-8]. The process is being commercialised by Metalysis in South Yorkshire, UK.

MER method

The MER approach [21] is an electrolytic method, which uses a composite anode of TiO_2, a reducing agent and an electrolyte, mixed with fused halides (Fig. 3). Projections are for titanium production at a significantly lower cost than the conventional Kroll process.

CSIRO technique

The CSIRO technique [22] builds upon the fact that Australia has some of the largest mineral and sand deposits in the world. In this approach cost-effective commercially pure titanium is produced in a continuous fluidised bed in which titanium tetrachloride is reacted with molten magnesium (the TiRO™ process), Fig. 4. They also have a proprietary process for producing alloys, with details unavailable at the present time. Continuous production of a wide range of alloys including aluminides and Ti-6Al-4V has been demonstrated on a large laboratory scale. The commercially pure titanium powder produced has been used to fabricate extrusions, thin sheet by continuous roll consolidation, and cold-sprayed complex shapes including ball valves and seamless tubing. Commercialisation of the process is now in the planning stage with a decision to proceed to the Pilot Plant stage likely to be taken in the near future.

Chinuka Process

The Chinuka Process [23] is being developed at the University of Cambridge, under the direction of Professor Derek Fray, with funding from White Mountain Titanium Corporation. It is exhibiting advantages over other, more conventional, titanium sponge production processes including comparatively low operating temperatures; a cheap, water soluble, non-toxic electrolyte and low power consumption (Fig. 5). The process is very similar to the MER process and has the main advantage that a high grade mineral or "metallurgical grade" TiO_2 is used. Compared to the Metalysis process, a eutectic of NaCl:KCl is used as electrolyte instead of $CaCl_2$ which reduces the operating temperature of the cell considerably (by approximately 200°C).

CSIR process

The CSIR process [24] is essentially aiming at producing titanium powder directly in a continuous metallothermic $TiCl_4$ reduction process in a molten salt reaction medium (Fig. 6). In principle it is possible to use any one of alkali or alkali earth metals as reducing metal, but there are advantages and disadvantages associated with every one of the choices.

ITP/Armstrong method

The ITP/Armstrong method [25] is continuous and uses molten sodium to reduce titanium tetrachloride, which is injected as a vapour (Fig. 7). The resultant powder does not need further purification and can be used directly in the conventional ingot approach. The powder is most efficiently utilised in the Powder Metallurgy technique. A range of alloys can be produced, including the Ti-6Al-4V alloy, as a high quality homogeneous product suitable for many applications. ITP currently operates an R&D facility in Lockport, Illinois, USA, and has broken ground on a four million pound per year expansion in Ottawa, Illinois, which is expected to ramp-up production in the near future and will produce both commercially pure titanium and Ti-6Al-4V alloy powder. The current approach to component manufacture and the ITP / Armstrong / Cristal Global proposed much simpler Powder Metallurgy route is shown in Fig. 8.

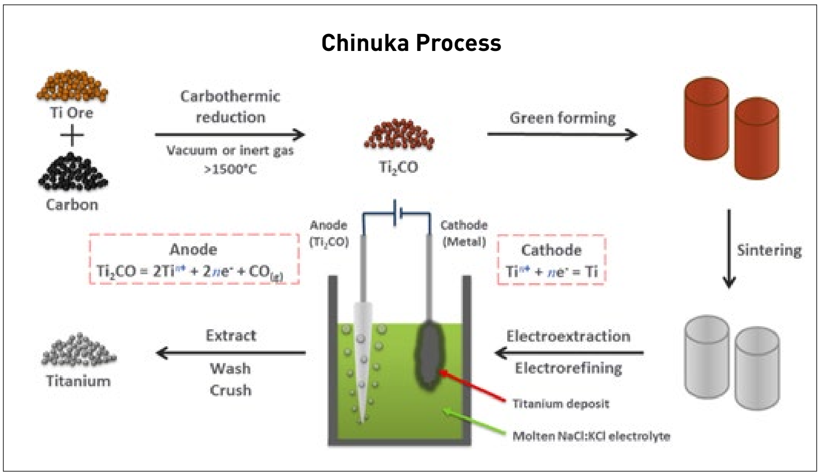


Fig. 5 The Chinuka process (Courtesy D J Fray, Cambridge University)

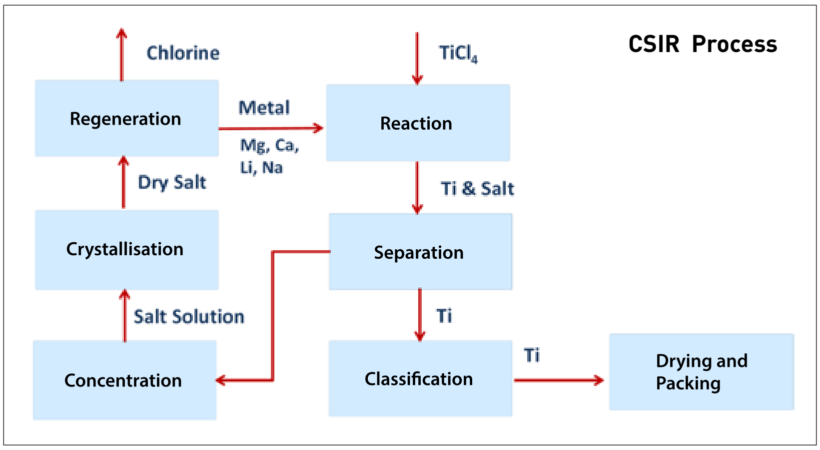


Fig. 6 Block flow diagram of the CSIR process (Courtesy Dawie Van Vuuren, CSIR)

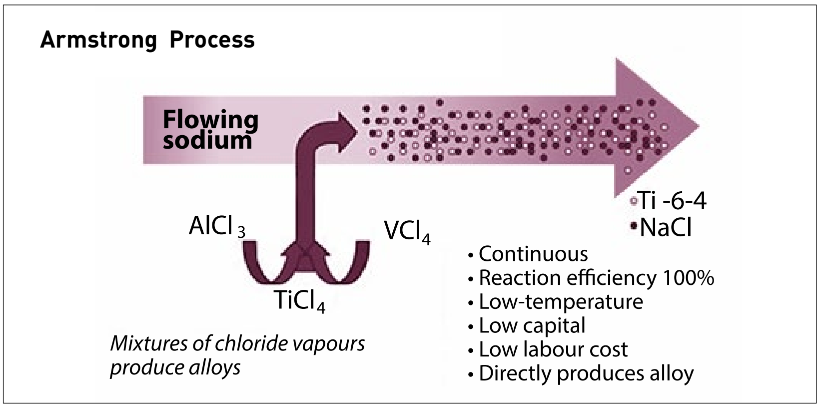


Fig. 7 A schematic of the (DARPA) Armstrong / International Titanium Powder (ITP) / Cristal Global process indicating the production of Ti-6Al-4V alloy powder (Courtesy Kamal Akhtar)

ADMA Products

In the ADMA Products approach [26] sponge titanium is cooled in a hydrogen atmosphere rather than the conventional inert gas (Fig. 9). The hydrogenated sponge is then easily crushed and in the hydrogenated condition can be compacted to a higher density than conventional low hydrogen sponge, with subsequent

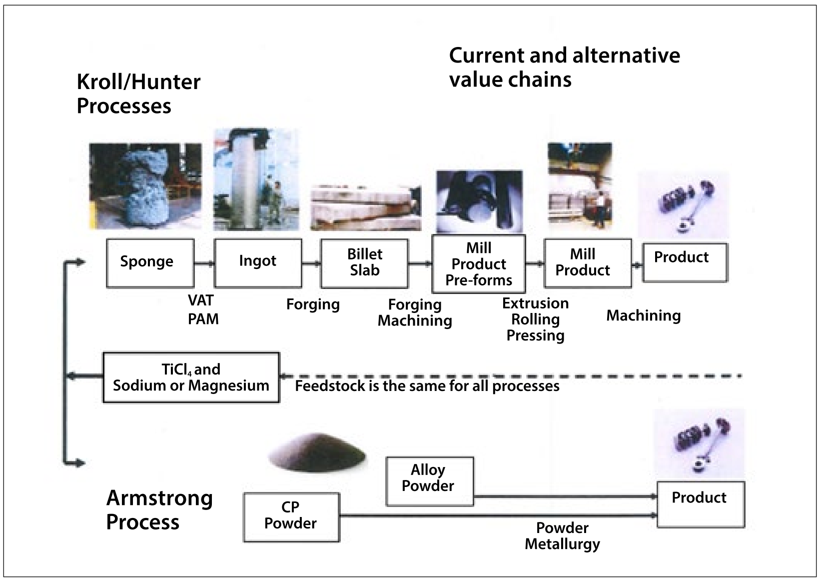


Fig. 8 The current approach to Component Manufacture and the ITP/Armstrong/Cristal Global proposed much simpler Powder Metallurgy route (Courtesy Kamal Akhtar)

hydrogen removal easily accomplished with a simple vacuum anneal. The remnant chloride content of the hydrogenated sponge is reported to be at low levels, helping to avoid porosity and enhancing weldability. Alloy powders (such as Ti-6Al-4V) can be produced by using V and Al chlorides simultaneously with $TiCl_4$ in calculated proportions. There are 14 patents covering this approach.

Estimates of the powder shipments (in all cases per year) have been made as HDH worldwide 1000–2500 mt (of which USA 200–400 mt) and spherical worldwide 150–350 mt (of which USA 20-50 mt).

Forming of titanium powder into near net shapes

The techniques generally available for production of near net shapes (NNS) are amenable for use with various types of titanium powders; these include conventional press-and-sinter, elastomeric bag Cold Isostatic Pressing (CIP) and ceramic mould or metal can Hot Isostatic Pressing (HIP) [1, 2, 15, 16]. For convenience, NNS will be divided into those produced using blended elemental (BE) powders and those produced from pre-alloyed (PA) powders, with the Additive Manufacturing approach discussed separately later.

The Blended Elemental approach

The blended elemental (BE) approach is potentially the lowest cost titanium PM process, especially if any secondary compaction step, for example HIP, can be avoided [1, 2, 15, 16]. In the BE approach angular titanium sponge fines (or titanium hydride powder) and master alloy (generally the 60:40 Al-V variety to produce the Ti-6Al-4V composition), are blended together, cold pressed and sintered to near full density. Use of titanium hydride allows densities very close to 100% to be obtained in components such as an auto connecting rod (Fig. 10) with mechanical properties at ingot metallurgy levels.

The blended element PM technology using hydride–dehydride (HDH) titanium powder produced by a Kroll sponge process is the key to the commercial success of Dynamet Technology's PM process [18]. This process is producing a wide range of affordable PM mill product forms and components. Dynamet Technology has developed critical specifications for its titanium and master alloy powders that control morphology, particle size, particle distribution and chemistry. The properties of the PM materials can be adjusted by modifications in these process parameters. The new powders that are under development may provide an opportunity for further reducing the costs of PM product if they can be processed to necessary density levels with properties equivalent or superior to baseline PM and wrought titanium. Finally, the cost of producing components from those powders must be competitive.

Fig. 9 Pilot scale unit at ADMA Products for manufacturing hydrogenated titanium powder, annual capacity is 250,000 lbs.

Fig. 10 Auto connecting rod fabricated via the blended elemental approach using hydrogenated titanium powder (Courtesy Orest Ivasishin, Ukrainian Academy of Sciences)

Chemical analysis of P/M Ti-6Al-4V CIP/Sinter/Rotary forged bars produced from ADMA TiH_2 powder

Ti-6Al-4V	Al	V	Fe	C	N	O	H	Ti	Other, Each	Other, Total
ADMA TiH_2	5.83	3.72	0.29	0.017	0.029	0.189	0.012	Bal.	<0.10	<0.40
ASTM B348	5.5-6.75	3.5-4.5	0.4	0.08	0.05	0.20	0.015	Bal.	<0.10	<0.40

PM Ti-6Al-4V	UTS, ksi	YS, ksi	Elongation, %	RA, %
ADMA TiH_2	154-155	141-142	15.8-16.5	38-40
AMS 4928R	135 min.	125 Min.	10 Min.	

Fig. 11 Ti-6Al-4V Round bar stock produced using the ADMA Products TiH_2 powder

Currently, the ADMA Products hydrogenated titanium powder manufacturing capacities are 250,000 lbs/year at their plant in Hudson, Ohio, with plans to produce 4 million lbs per year next year and 15 million pounds per year five years from now at a new facility in Sheffield Village, Ohio [26, 27]. Meanwhile, the major aircraft companies and the US Department of Energy and Department of Defence agencies have tested this material and reported that the mechanical properties of the PM Ti alloys meet AMS specification (Fig. 11) and meet or exceed titanium wrought alloys made by conventional ingot metallurgy approaches.

Examples of how the BE approach has been used to produce valves for production models of the Toyota Altezza automobile, golf club heads, and softball bats are shown in Figs. 12-14 [1, 2, 15, 16] respectively.

Fig. 12 The Toyota Altezza, 1998 Japanese car of the year, the first family automobile in the world to feature titanium valves. Ti-6Al-4V intake valve (left) and TiB/Ti-Al-Zr-Sn-Nb-Mo- Si exhaust valve (right) (Courtesy Toyota Central R & D Labs, Inc.)

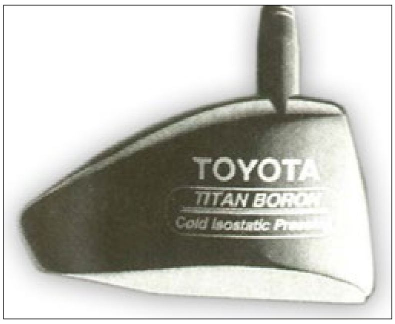


Fig.13 Titanium metal matrix composite golf club head (reinforced with TiB). (Courtesy Toyota Central R & D Lab Inc.).

Fig. 14 This softball bat from Dynamet Technology, Inc. has a Powder Metallurgy titanium alloy outer shell

The CHIP process

The CIP-Sinter or CHIP (CIP-Sinter-HIP) process [18] is used by Dynamet Technology to produce near net-shape parts for finish machining to high tolerance configurations (Fig. 15). These processes can also be used to make forging preforms or mill product shapes for subsequent processing such as billet for casting, extrusion or hot rolling. In the case of as-sintered material full density is achieved during subsequent processing.

The CHIP process is a green manufacturing technology [18] that has proven to be an acceptable process for producing military, industrial and medical components. This advanced PM process uses titanium powder, typically Kroll process HDH powder, blended with master alloy powder such as aluminium-vanadium master alloy powder. The blended powder is compacted to shape by Cold Isostatic Pressing (CIP) in elastomeric tooling. With proper selection of powders, well designed CIP tooling and appropriate pressing conditions a shaped powder

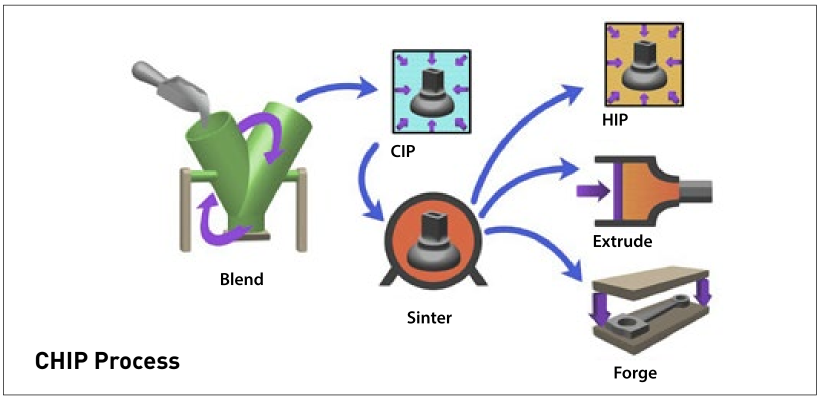


Fig. 15 Schematic of Dynamet Technology Inc. CHIP process (Courtesy Stan Abkowitz)

compact can be produced and readily extracted from the PM tooling with sufficient green strength for handling. It must also have sufficient uniformity and intimate contact of the powder particles for densification and homogenous alloying in the subsequent sintering process.

A wide range of shapes have been produced with size only limited by the capacity of the equipment (Fig. 16) [28]. The size of the CIP is usually the limiting factor since vacuum furnaces and HIP units are available in larger sizes than are high pressure CIP units. Size capability also depends on the powder fill characteristics, product configuration and tooling parameters. Successful products can range from a few grams to hundreds of kilos.

The major cost benefits of this clean, energy efficient manufacturing process are that it uses relatively low cost raw materials, avoids costly melt processes and results in relatively little material lost during processing. The capability to produce to a near-net shape conserves raw material and also reduces costs for machining to finished parts. The cold pressed compacts are sintered in vacuum to high or nearly full density. Alloying of the titanium with the desired additional elements is accomplished by solid state diffusion during the sintering process. By selecting the proper powders and sintering parameters, a homogeneous alloyed material with sufficiently high density, free of interconnected porosity, is achieved.

The sintering process was historically established to reach a minimum density level at which the material had no interconnected porosity. At this density threshold the material could be Hot Isostatically Pressed (HIPed) without the processing expense of HIP encapsulation, making the HIP process economically viable. Through recent developments the capability to reach greater than 98% sintered density has been achieved. This results in as-sintered tensile properties (Table 3) [18] that are equivalent to wrought properties and superior to castings. This reduces the need for the HIP operation and further strengthens the economic advantage of this PM CIP-Sinter manufacturing technology.

As pointed out by personnel from Dynamet Technology [28] the compatibility of titanium with graphite fibres in advanced composite aircraft structures has resulted in increased use of titanium at the expense of aluminium in aircraft parts. There is a high galvanic potential between aluminium and graphite and, as a result, the aluminium can be corroded away in the presence of moisture. In addition, the coefficient of thermal expansion (CTE) of aluminium is higher than that of graphite. This CTE mismatch can result in very high loading. Titanium's CTE more closely matches that of graphite alleviating this concern. The increased demand for titanium alloys in commercial aircraft (the Boeing 787 Dreamliner has an airframe consisting of more than 20% titanium) has heightened the aircraft industry's interest in PM Ti because of PM Ti's near-net shape capability and reduced machining that offers the industry a significant cost advantage over conventional ingot metallurgy titanium mill products.

Boeing and Dynamet Technology have worked closely together over

	% of Theoretical Density	Ultimate Tensile Strength MPa (ksi)	Yield Strength MPa (psi)	Elongation (%)
AMS 4928 (Min)		896 (130)	827 (120)	10
Typical Wrought		965 (140)	896 (130)	14
Typical PM CIP-Sinter	98%	951 (138)	841 (122)	15
Typical PM CHIP	100%	965 (140)	854 (124)	16

Table 3 Ti-6Al-4V alloy CHIP and AMS 4928 tensile properties

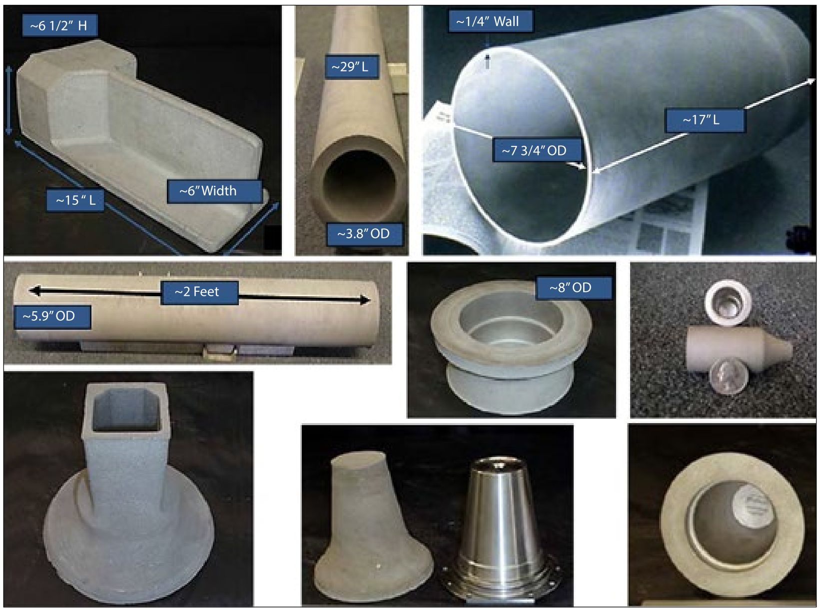


Fig. 16 Examples of near-net titanium shapes produced by Dynamet Technology, Inc.

the past few years to qualify the Ti-6Al-4V alloy for use on Boeing commercial aircraft. As noted again by Dynamet Technology personnel they have collaborated with Boeing in generating a Boeing Material Specification for the PM Ti-6Al-4V material. Mechanical properties meet AMS minimum requirements (Table 3) As a result of this effort Boeing Material Specification 4, *BMS7-393B, Titanium 6Al-4V, Pressed and Sintered Powder Compacts*, was released on January 30, 2012 with Dynamet Technology Inc. currently as the sole qualified manufacturer on the Qualified Products List (QPL) for this specification. This breakthrough will enable Dynamet's PM Ti products, from a few grams to hundreds of kilos, to be used as a substitute for a variety of wrought titanium airframe components on commercial Boeing aircraft.

The ADMA Products hydrogenated titanium process

The use of titanium hydride powder instead of titanium sponge fines has led to the achievement of essentially 100% density, using a simple cost-effect press-and-sinter technique, in complex parts [26, 27, 29, 30]. In this work, hydrogenated non-Kroll powder (by cooling the sponge produced in a Kroll process with hydrogen rather than the conventional inert gas a lower cost titanium hydride powder has been produced by ADMA Products) was utilised along with 60:40 Al:V master alloy to produce components comprised of the Ti-6Al-4V alloy. The press-and-sinter densities achieved using this novel fabrication technique are shown in Fig. 17. The associated microstructure and typical mechanical properties are shown in Fig. 18 and Table 4 (after cold pressing, sintering, forging and annealing) respectively. The mechanical properties compare well with those exhibited by cast-and-wrought product. The low cost of this process in combination with the attractive mechanical properties make this approach well suited to the cost-obsessed automobile industry and a number of auto components produced by this technique are shown in Fig. 19.

In Kroll's process, the removal of Ti sponge from the retort and its subsequent crushing is time and energy intensive. In comparison, ADMA's process produces TiH_2 that, unlike Ti sponge, is very friable, and

PM Ti-6Al-4V	Ultimate Tensile Strength MPa (ksi)	Yield Strength,MPA (ksi)	Elongation %	Reduction of Area, %
3.5 cm (1.376") thick	994-1028 (144-149)	911-938 (132-136)	14.0 – 15.5	34 – 38
ASTM	897 (130)	828 (120)	10	25

Table 4 Room temperature tensile properties of a hydrogenated titanium compact (after dehydrogenation)

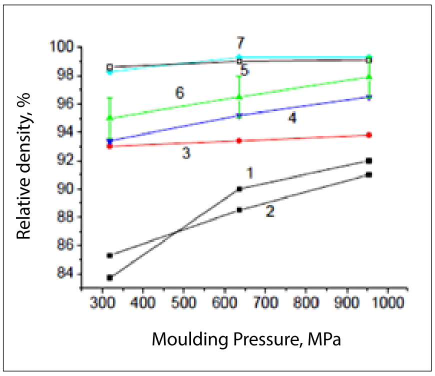


Fig. 17 Density of Ti-6Al-4V compacts after sintering. Conditions 5 and 7 used hydrided powder and show by far the highest and most uniform densities (Courtesy ADMA Products)

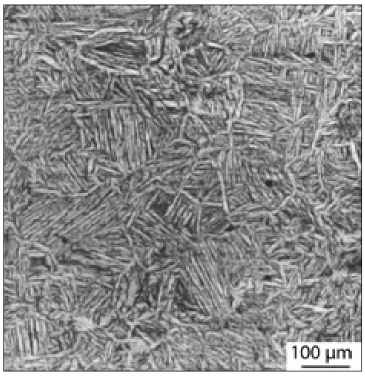


Fig.18 Microstructure of sintered Ti-6Al-4V (Courtesy ADMA Products)

Ti-6Al-4V parts

1) Connecting rod with big end cap
2) Saddles of inlet and exhaust valves
3) Plate of valve spring
4) Driving pulley of distrib-uting shaft
5) Roller of strap tension gear
6) Screw nut
7) Embedding filter, fuel pump
8) Embedding filter

Fig. 19 Ti-6Al-4V parts produced using a press-and-sinter approach and titanium hydride (Courtesy Ukrainian Academy of Sciences)

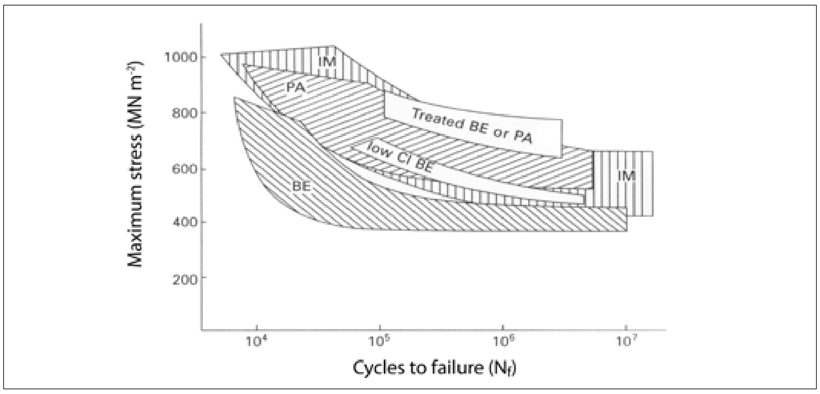


Fig. 20 Fatigue data scatterbands of conventional BE, low chloride BE, treated low chloride BE and PA, compared with wrought annealed material

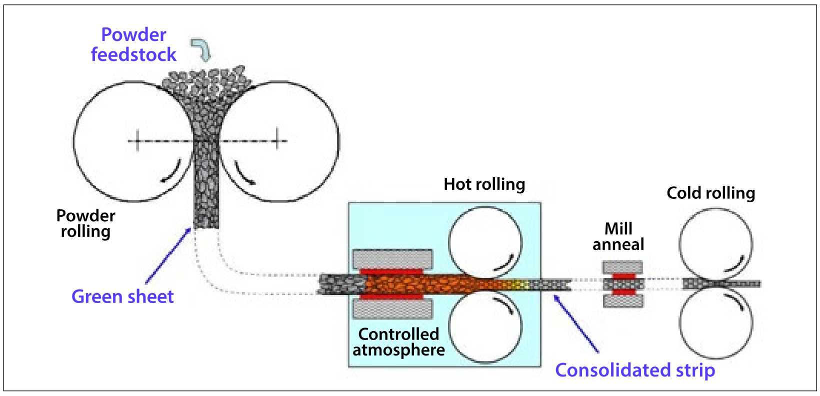


Fig. 21 Schematic of the process used to produce commercially pure titanium sheet at CSIRO [22]

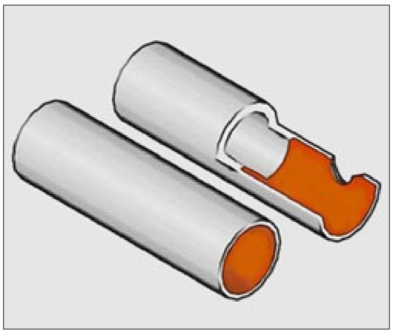


Fig. 22 Shot sleeve liners for use in the aluminium die-casting industry produced from CermeTi material (Courtesy Dynamet Technology, Inc.)

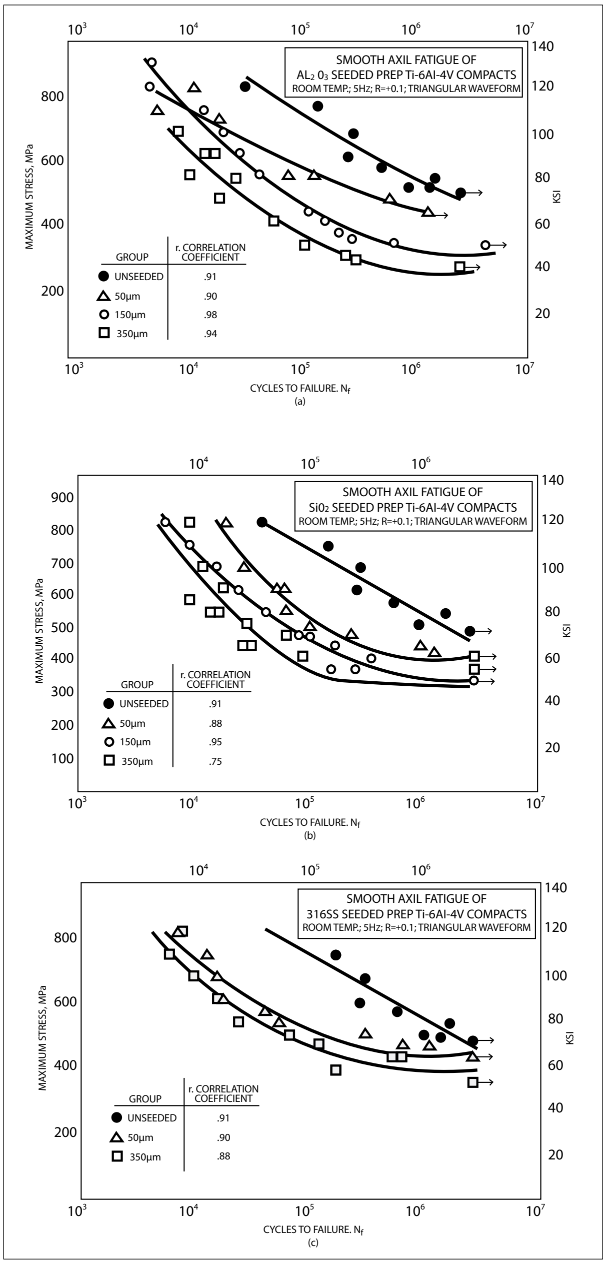


Fig. 23 Data points and computer generated S-N curves for all fatigue specimens initiated at seeded (a) Al_2O_3, (b) SiO_2, and (c) 316 SS contaminants, in comparison to contaminant-free unseeded baseline [29]

easily removed from the retort with no need for expensive sizing operation. ADMA's vacuum distillation processing time is also at least 80% less than in Kroll's process since phase transformations / lattice parameter changes of the hydride sponge, in the presence of hydrogen, accelerate the distillation removal of $MgCl_2$. Finally, atomic hydrogen is released during sintering-dehydriding of the TiH_2 powder and acts as a scavenger for impurities (oxygen, chlorine, magnesium etc.) resulting in titanium alloys with low interstitials that at least meet properties of ingot metallurgy alloys.

A comparison of the S-N fatigue behaviour of BE and pre-alloyed material with cast and wrought product is shown in Fig. 20 [15, 16].

Powders can be subsequently fabricated to other product forms, such as sheet (Fig. 21). Alloy sheet can be fabricated in a similar manner by adjusting the feed stock to a mixture of titanium powder and alloying additions.

Metal Matrix Composites

Both continuously and discontinuously reinforced titanium components have been produced using PM approaches. An example is a titanium MMC ring fabricated from HIP densified plasma sprayed tapes by IMT-Bodycote.

The blended elemental technique has also been used by Dynamet Technology Inc for the fabrication of MMCs utilising particulate and a combined Cold and Hot Isostatic Pressing (CHIP) process or forging, extrusion and rolling of the CHIP preform [18]. The CermeTi family of titanium alloy matrix composites incorporates particulate ceramic (TiC or TiB_2) or intermetallic (TiAl) as a reinforcement with minimal particle/matrix interaction. A mechanical property comparison of CermeTi material with PM Ti-6Al-4V shows the reinforced material having a higher Yield Strength of 965 MPa (140 ksi) compared to 896 MPa (130 ksi) but lower Elongation (3% compared with 14%) [1]. A shot sleeve liner for aluminium die-casting has been successfully fabricated using CermeTi material which is now standard equipment in the industry (Fig. 22). Dynamet Technology has also made seven layer armour and a dual hardness gear from CermeTi material [18].

The pre-alloyed approach

The pre-alloyed approach (PA) involves use of pre-alloyed powder, generally spherical in shape, which has been produced by melting, either by a technique such as the plasma rotating electrode processing (PREP) or gas

Fig. 24 Near net shape Ti-6Al-4V engine casing fabricated using the pre-alloyed metal method (Courtesy Victor Samarov, Synertechpm)

Fig. 25 Selectively net shape ELI Ti-6Al-4V Impeller for a turbo-pump of a rocket engine fabricated using the pre-alloyed metal method (Courtesy Synertechpm / P&W Rocketdyne)

atomisation (GA), followed by hot consolidation (generally by HIP) [1,2,15,16,31]. Initial complex shape making work was carried out using ceramic moulds [1,2,15,16]. However partly because of concerns that ceramic or other particles could get into the titanium parts fabricated using the ceramic mould process with a degradation in mechanical properties, particularly S-N fatigue, this process has been discontinued (Fig. 23) [32]. However parts produced using a shaped metal can and removable mild steel inserts (removed by chemical dissolution) are commercially available (Figs. 24 & 25) [31]. Commercial practice is carried out by pouring titanium powders under clean room conditions into a metal can, with metal inserts, followed by compaction.

Despite the 30-35% volume shrinkage, typical for HIP of PA powders, advanced process modelling allows net surfaces to be achieved and minimal machining stock on the near net surfaces. Also these near net shape titanium parts can be made up to the size of existing HIP furnaces, for example up to two meters, considerably larger than the capabilities of the other technologies discussed [31].

These parts exhibit mechanical properties superior to conventional cast and wrought (ingot metallurgy) components because of the refined microstructure and lack of directionality (Figs. 26, 27 and Table 5). Fig. 26 shows actual tensile strength levels obtained in cast and wrought product compared to data from PM product. However the minimum values (which are used in design) for the PM material is above that for the conventionally fabricated material (Fig. 27). Fracture toughness of the PM product is superior to cast and wrought material (Table 5).

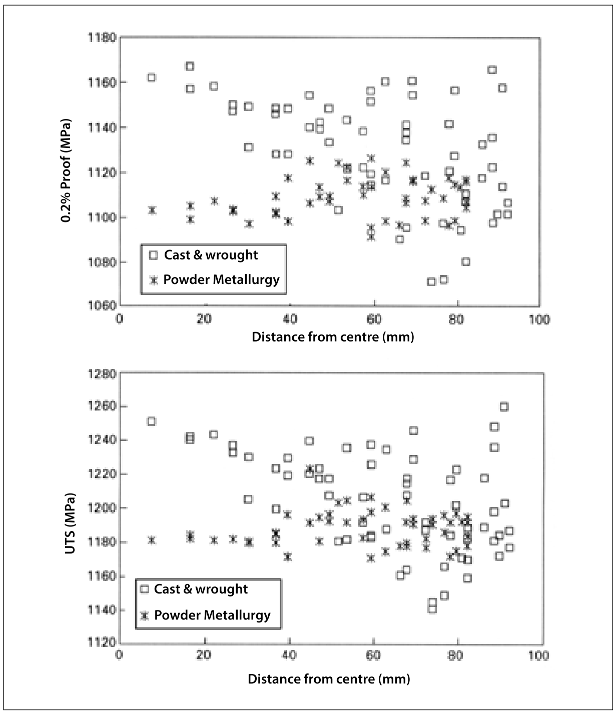


Fig. 26 Comparison of ingot and Powder Metallurgy tensile properties (Courtesy Prof. Igor Polkin, VILS, Russia)

Ti-6Al-4V	K_{IC} ($MNm^{-3/2}$)
Powder Metallurgy Specimen 1	94.0
Powder Metallurgy Specimen 2	96.5
Powder Metallurgy Specimen 3	92.5
Forged Specimen	55.0

Table 5 Fracture toughness of PM material and conventionally forged material (Courtesy Rolls-Royce, UK)

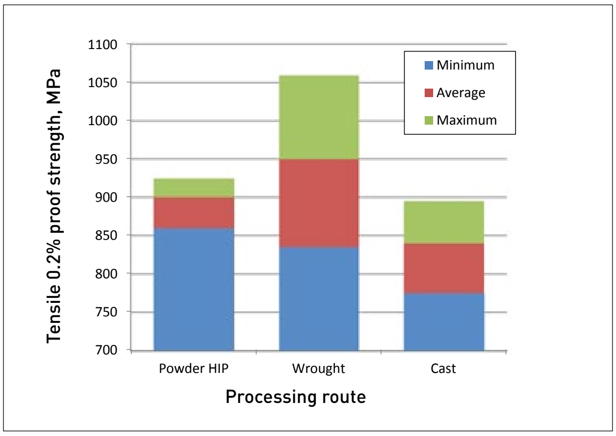


Fig. 27 Comparison of powder HIPed, wrought and cast tensile properties

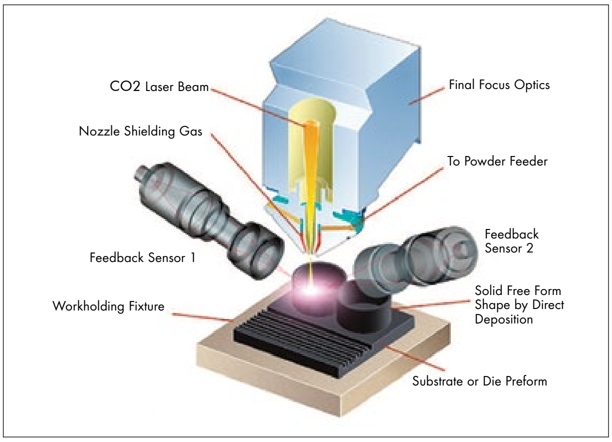


Fig. 28 Schematic showing Direct Metal Deposition (DMD) technology (Courtesy DM3D Technology)

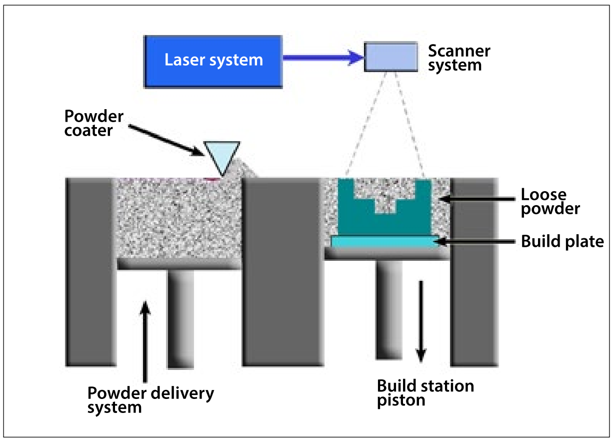


Fig. 29 Schematic showing powder bed fusion technology (Courtesy Jim Sears)

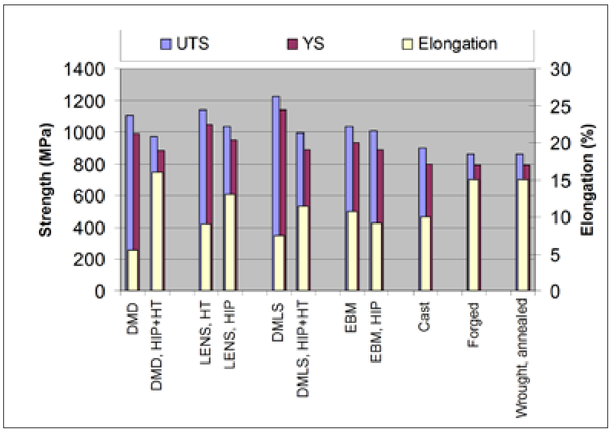


Fig. 30 Tensile strength, yield strength and elongation of Ti-6Al-4V alloy built using various AM processes. DMD-Direct Metal Deposition, LENS-Laser Engineered Net Shaping DMLS-Direct Metal Laser sintering, EB-Electron Beam Melting, HIP-Hot Isostatic pressing, HT-Heat treatment

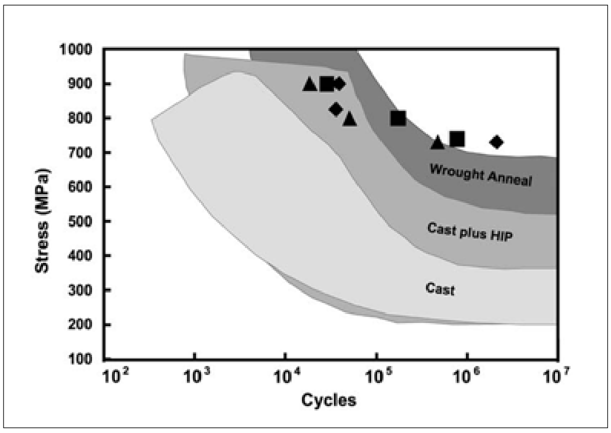


Fig. 31 Comparison of Room Temperature fatigue properties of Ti-6Al-4V processed by AM and a comparison with conventionally fabricated Ti-6Al-4V. ■,♦ and ▲ represent properties in the three orthogonal directions, x, y and z respectively (Courtesy of EADS/Jim Sears)

Additive Manufacturing

Additive Manufacturing (AM) uses the principle of slicing a solid model in multiple layers, storing the data in a computer, and building up the part layer by layer with powder following the sliced model data [33]. There are two basic approaches to AM, Direct Energy Deposition (DED) shown schematically in Fig. 28 and Powder Bed Fusion (PBF) illustrated in Fig. 29. The DED approach has the advantages of large build envelopes, higher deposition rates, the capability of multiple material deposition in a single build and the ability to add material to existing parts (including repair of parts). The PBF technique allows buildup of complex features, hollow cooling passages and production of high precision parts.

Tensile strength, yield strength and elongation of Ti-6Al-4V alloy built using various AM processes is shown in Fig. 30. All of the processes show strength levels superior or comparable to conventional material (cast, forged and wrought). As built materials in laser based processes such as DMD, LENS and DMLS exhibit less ductility due to the formation of the martensite phase, the ductility can be improved through subsequent HIPing and/or heat treatment operation. As a result

Fig. 32 BALD bracket for Joint Strike Fighter (JSF) built using EBM technology (Courtesy ORNL, TN)

of reduced residual stress, EBM processed Ti-6Al-4V shows greater ductility when compared to laser processed Ti-6Al-4V. The S-N fatigue performance of AM is at or even a little above conventional material levels (Fig. 31).

The main issue influencing growth in deployment of AM for titanium alloys relates to raw material supply. Firstly, with material cost being typically 40-50% of total manufacturing cost for AM titanium, material cost is a major issue. Material supply chain is an issue for both powder and wire; sustainable sources are not always available and supplies of certain alloys have limited availability.

The direct manufacturing ability of additive manufacturing technologies also helps to reduce manufacturing cost in the case of high buy-to-fly ratio parts. Researchers at the Oakridge National Laboratory built a Ti-6A-4V Bleed Air Leak Detect (BALD) bracket for the Joint Strike Fighter (JSF) engine using EBM technology (Fig. 32) [33]. Traditional manufacturing from wrought Ti-6Al-4V plate costs almost $1000/lb due to a high (33:1) buy-to-fly ratio as opposed to just over 1:1 ratio for the AM built part. Estimated saving through AM is about 50%. The advantage of attaching features is demonstrated in Fig. 33, and the capability of using AM in repair of a part is illustrated in Fig. 34 [33].

Fig. 33 Fan case produced by adding features with AM to a forged perform (Courtesy Jim Sears)

Fig. 34 AM repair of gas turbine components (Courtesy Jim Sears)

Spray forming

Spray forming can involve either molten metal or solid powder. Because of its very high reactivity the challenges associated with molten metal spraying of titanium are quite considerable. However, both spray forming in an inert environment and under reactive conditions have been achieved with appropriately designed equipment.

Recently there has been increased interest in cold spray forming involving solid powder particles [22]. Cold spray (<500°C) can produce both monolithic "chunky" shapes and coated components. In this process, solid powder is introduced into a deLaval-type nozzle and expanded to achieve supersonic flow. Powders are in the range of 1-50 microns, at relative low temperatures (<500°C) with a velocity in the range of 300-1,200 m/s (Fig. 35) [22]. Coatings can be applied even to the inside of tubular components. The density of the sprayed region is less than full density, but this can be increased to 100% density by a subsequent HIPing operation.

Fig. 35 Components produced at CSIRO by cold spraying commercially pure powder (Courtesy John Barnes)

This technique is also very useful in bonding together normally difficult to bond metals such as titanium and steel (Fig. 36).

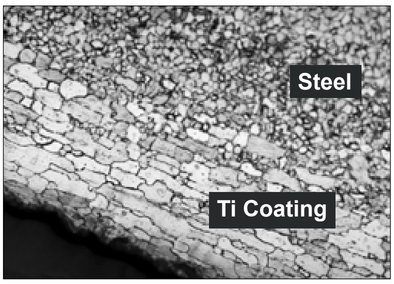


Fig. 36 Optical photomicrograph showing the excellent bonding of titanium to steel (Courtesy Ktech)

Fig. 37 The Boeing 787 Dreamliner, containing over 20% titanium, which could see components fabricated by the blended elemental titanium Powder Metallurgy approach

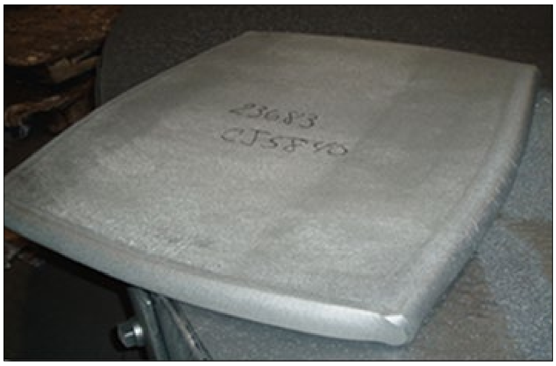


Fig. 38 Cold press, sinter and hot rolled pre-form (weighing 95 kg / 210 pounds) for commanders hatch forging on a Bradley Fighting Vehicle (Courtesy of ADMA Products)

Future thoughts on the developments and opportunities for Ti-PM

Over the past 30 years a great deal of money, much of it from US government sources, has been spent in attempting to circumvent the high cost of titanium components for aerospace and terrestrial applications. Despite a few successes with lower integrity BE parts and recent advances in PIM, the overall market is small, in total perhaps 20,000 pounds per year maximum world-wide.

However, a variety of high quality, low cost powders should be available soon. These powders are basically angular in shape and should thus be usable in the blended elemental approach. If the morphology can be changed to a spherical or near-spherical shape (giving good flow and packing - around 60% or greater) then they should be amenable to production of large (hundreds of pounds) complex components by the pre-alloyed / HIP approach in a cost effective manner.

There have also been a number of developments which should lead to a reasonable growth of products produced by the PM process.

It would seem that the Ti PIM market is partially stalled, with the cost issue for quality small spherical powder being the major problem. It has been estimated that for 2013 the Ti PIM market is seven to ten tons globally and since prices are not falling much (with the current high priced powders) growth at best is projected 6-8% per year for the PIM method [32].

There appear to be three areas where growth can occur. Firstly, small parts (less than one pound in weight) by the PIM method, as noted above [35].

Secondly, larger parts using the BE and PA (especially with the availability of lower cost spherical/near-spherical pre-alloyed powder) techniques. The current world-wide production of spherical powder at 150–350 mt per year is likely to show at least a tenfold increase in the next five to ten years (for the PA approach) and the market for the BE technique has been projected to increase from nominal amounts to 2,000-20,000 mt in the next five to ten years [36].

The third area for growth lies in larger parts using the Additive Manufacturing approach, which could also benefit from the availability of cost-affordable spherical / near-spherical pre-alloyed powder. Most of the work on Ti AM at present is developmental, however a market of millions of pounds is projected in five to ten years from now [37].

Looking into a murky crystal ball the titanium BE Powder Metallurgy market could expand to the millions of pounds per year in the next five to ten years with applications in aerospace, led by the news that Dynamet Technology have been qualified to produce titanium PM parts for Boeing [28]. This should lead to flying applications on Boeing systems such as the 787 Dreamliner (Fig. 37). Other developing applications for BE material include sporting equipment (golf clubs in particular), medical, automotive, as armour on land based military vehicles, chemical processing equipment and in oil and gas exploration / production.

Blended elemental applications are also likely to grow especially with

Fig. 39 Various army systems which could see use of hydrogenated titanium blended elemental powder components (Courtesy Timet)

innovative approaches such as use of hydrogenated powder to produce uniformly high densities [29,30] including large armoured vehicle parts (Fig. 38) for use in a variety of army systems (Fig. 39).

There are barriers to overcome using the PA approach. Here the competition is with critical components produced by the "tried and true" cast-and-wrought or the direct casting approach. Recent developments suggest that immediate applications for PA titanium are in complex parts, the very difficult to fabricate TiAl intermetallic alloys, and in metal matrix composite concepts.

The Additive Manufacturing approach should also see significant growth, in competition with the BE and PA techniques.

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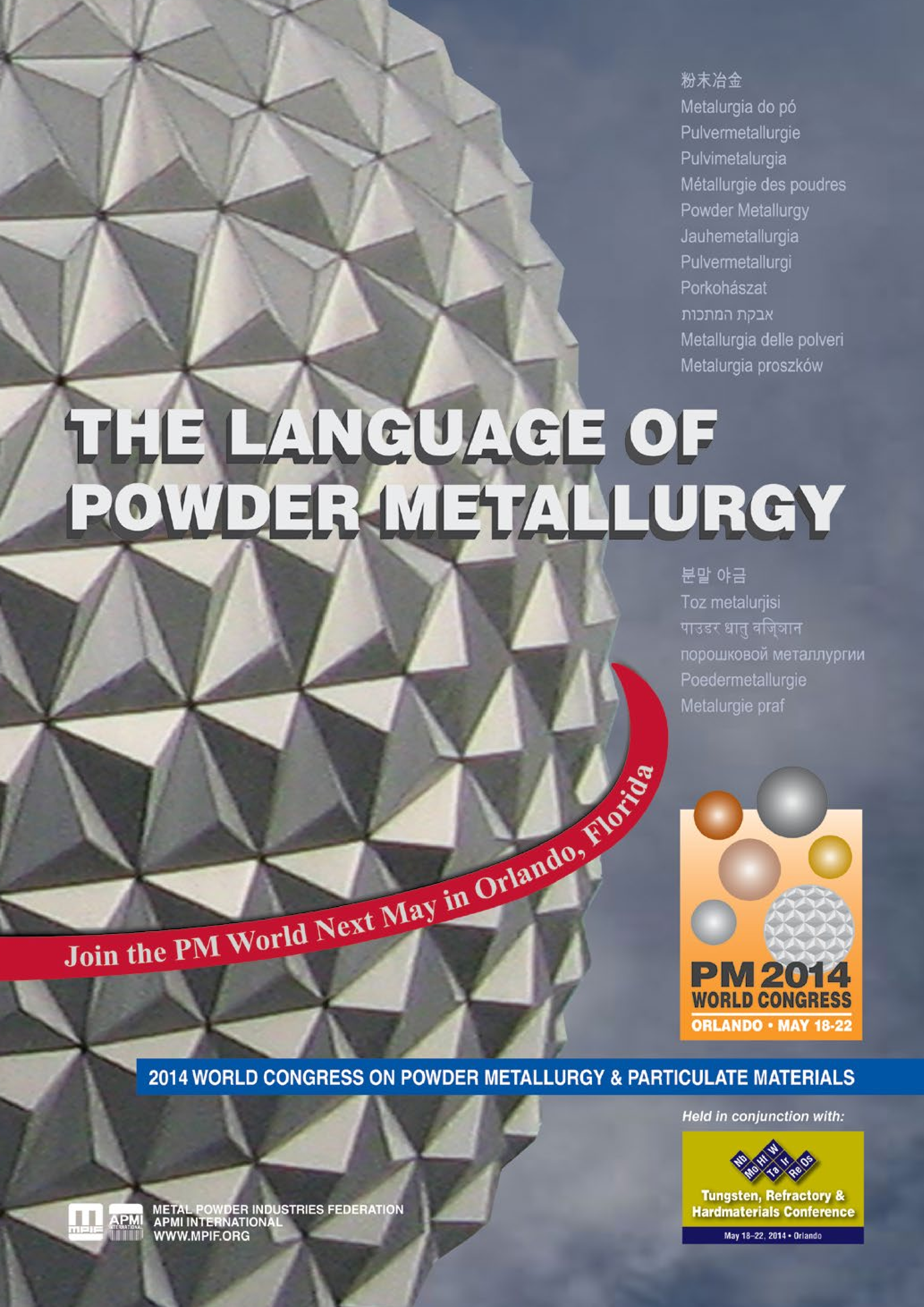

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Pulvermetallurgie
Pulvimetalurgia
Métallurgie des poudres
Powder Metallurgy
Jauhemetallurgia
Pulvermetallurgi
Porkohászat
אבקת המתכות
Metallurgia delle polveri
Metalurgia proszków
THE LANGUAGE OF POWDER METALLURGY
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Powder Metallurgy standards: Supporting the growth of a global industry

The development of standards for use in the Powder Metallurgy industry dates back to the 1930s. It wasn't however until 1968 that the International Standards Organisation (ISO) began to adopt PM standards via the formation of Technical Committee TC 119 and today the work of that committee continues. In this article Dr Brian James looks at why the industry needs standards and highlights what purpose they serve. The development of PM standards, greatly influenced by national bodies and PM trade associations, is discussed. The article also reviews recent developments and highlights ongoing activities as standards evolve and adapt to new processes and technologies.

Over 70% of the ferrous Powder Metallurgy structural parts produced are used in the automotive industry. One of the key factors that led to the introduction of the automated assembly line was the standardisation of the production of the individual components that were to be assembled. Prior to that everything was custom built. Standardisation is essential for highly automated production processes. Standardised methods of testing lead to improved communication between powder suppliers and parts makers, and between the parts makers and their customers, the end-users of the PM parts that they make. When considering standard tests it is important to understand the precision of the test in question. How repeatable is the test and how reproducible when multiple laboratories perform the test?

We should first draw a distinction between Material Standards and Test Method Standards (Table 1).

A Material Standard is a specification that defines an explicit set of requirements to be satisfied by that material [1], for example chemical composition limits and mechanical property requirements. A Test Method is a definitive procedure that produces a test result [1]. In the field of PM there are Test Methods for powders as well as Test Methods for green compacts and for compacted and sintered PM parts.

Standard Specification	An explicit set of requirements to be satisfied by a material, product, system or service
Standard Test Method	A definitive procedure that produces a test result
Standard Practice	A set of instructions for performing one or more specific operations that does not produce a test result
Standard Classification	Systematic arrangement or division of materials, products, systems, or services into groups based on similar characteristics such as origin, composition, properties, or use
Standard Guide	An organised collection of information or series of options that does not recommend a specific course of action

Table 1 Terminology used to identify ASTM International standards

In addition to material standards and test methods there are also standard practices, guides, and classifications [1]. A Standard Practice provides a definitive set of instructions for performing one or more specific operations that does not produce a test result. A Standard Guide is a compendium of information or a series of options that does not recommend a specific course of action. A Standard Classification is a systematic arrangement or division of materials, products, systems, or services into groups based on similar characteristics such as origin, composition, properties, or use.

"The organisations that are currently most active in the development of standards for Powder Metallurgy are ASTM International, MPIF, EPMA, and ISO"

The development of PM standards

Lenel published a paper in 1978 that covered the history, development and present status of PM standardisation in the United Sates as well as internationally [2]. Informal standards were developed in the 1930s but the progress of standardisation greatly increased during the 1940s when the work was formalised through the formation of official standards committees; ASTM Committee B09 in 1944, followed by the Metal Powder Industries Federation and the Cemented Carbide Producers Association. Standards similar to those in the United States were adopted in a number of countries in Europe (United Kingdom – BSI; Germany – DIN; France – AFNOR; Soviet Union – GOST) as well as in Japan. PM standards development at the International Standards Organisation (ISO) did not start formally until 1968 with the formation of Technical Committee TC 119 following a meeting in Moscow in June 1967 to consider the formation of such a committee. An excellent review of the participation of the United States in ISO/TC 119 activities has been presented by Pease [3].

The organisations that are currently most active in the development of standards for PM are the American Society for Testing and Materials (ASTM) International, Metal Powder Industries Federation (MPIF), European Powder Metallurgy Association (EPMA), and International Standards Organisation (ISO).

American Society for Testing and Materials International (ASTM)

The ASTM International committee with the responsibility for the development of PM standards is Committee B09. It has responsibility for the formulation of specifications and methods of test for metal powders and metal powder products. Committee B09 has a number of subcommittees as can be seen in Table 2.

ASTM International Committee B09	
B09.01	Terminology
B09.02	Base Metal Powders
B09.03	Refractory Metal Powders
B09.04	Bearings
B09.05	Structural Parts
B09.06	Cemented Carbides
B09.09	US Technical Advisory Group for ISO/TC 119 on Powder Metallurgy
B09.11	Near Full Density Powder Metallurgy Materials
B09.98	Long Range Planning and Awards

Table 2 Subcommittees of the ASTM International committee B09, responsible for the development of PM standards

ASTM Committee B09 meets twice a year to discuss responses to Subcommittee and Main Committee ballots. Members of the committee comprise producers of powders, makers of PM parts, users of PM parts, as well as consultants to the PM industry. ASTM International requires full consensus and all negative votes must be addressed and resolved either by withdrawal of the negative vote following discussion or, in rare instances, via a motion to deem the negative non-persuasive, with the reason for the non-persuasive nature of the negative being clearly stated in the motion.

The participation of the United States in ISO/TC 119 must be through the USA member body, which is ANSI (American National Standards Institute). ANSI was given this position as coordinator of standards making activities by an act of the US Congress. ANSI has designated ASTM subcommittee B09.09 as the group responsible for coordinating the position of the US on matters relating to PM. When US representatives from B09.09 wish to attend a Subcommittee or Plenary meeting of ISO/TC 119 they have to notify ANSI who issue a formal letter of appointment directed to the Secretariat of the particular Subcommittee.

ANSI receives all formal communication from ISO. The Chairman of Subcommittee B09.09 appoints liaison consultants for each ISO/TC 119 Subcommittee. The liaison consultants review the activities for each TC 119 Subcommittee during the B09.09 Subcommittee meetings and indicate the voting position taken by the US on each ballot item. A working group meeting precedes the actual meeting of Subcommittee B09.09 during which any issues of concern with the proposed ISO documents are reviewed and discussed and the US position is established.

All ASTM standards are subject to periodic review (five year cycle). Test methods are required to contain precision and bias statements. The precision consists of the repeatability of the test when conducted by the same operator on the same equipment in the same laboratory, and the reproducibility of the test; how repeatable the test is when conducted by different operators in different laboratories. Bias is not available for the PM test methods as there is no material having an accepted reference value available.

Metal Powder Industries Federation (MPIF)

The Metal Powder Industries Federation is a not-for-profit association formed by the PM industry to advance the interests of the metal powder producing and consuming industries. It is a federation of six trade associations that are concerned with some aspect of Powder Metallurgy, metal powders, or particulate materials. The six associations are: Powder Metallurgy Parts Association (PMPA), Metal Powder Producers Association (MPPA), Powder Metallurgy Equipment Association (PMEA), Metal Injection Moulding Association (MIMA), Refractory Metals Association (RMA) and Isostatic Pressing Association (IPA).

The MPIF Standards Committee is responsible for the development and maintenance of MPIF Standard 35 (Table 3), of which the Materials Standards for PM Structural Parts [4] derivative is probably the most widely used PM material standard in the world. The MPIF Standards Committee is also responsible for the development and maintenance of standard test methods related to Powder Metallurgy products. These standards are published in the *MPIF Standard Test Methods for Metal Powders and Powder Metallurgy Products* [5] and, because of its black and yellow cover, this book is sometimes referred to as the "bumble bee book."

In addition to the MPIF Standard 35 derivative mentioned above, there is also an *MPIF Standard 35, Materials Standards for PM Self-Lubricating Bearings* [6]. This standard is developed and maintained by the Bearings Subcommittee of the MPIF Standards Committee. *MPIF Standard 35, Materials Standards for P/F Steel Parts* [7] is the responsibility of the Powder Forging Subcommittee of the MPIF Standards Committee. The MPIF Standards Committee typically meets twice per year with additional meetings scheduled as deemed necessary. The Bearings and Powder Forging Subcommittees meet when required to update their respective versions of MPIF Standard 35.

The MPIF Standards Committee comprises individuals who represent MPIF member companies that are involved with making PM parts (PMPA) and with making metal powders (MPPA). Standards that are developed by the Committee are subject to ballot by the six trade associations that comprise MPIF. All negatives and any comments received on ballot are reviewed and addressed by the Standards Committee. Test method standards are subject to review on a periodic basis, typically at least every five years. The materials standards are also subject to periodic review, with timing dependent on the availability of new data for existing materials or data for materials not previously covered in the standard. *MPIF Standard 35, Materials Standards for PM Structural Parts* has been updated quite frequently with eight new editions from 1990 to date. The latest edition was published in 2012.

In addition to listing materials standards for ferrous and non-ferrous PM materials *MPIF Standard 35, Materials Standards for PM Structural Parts* also contains a section on Engineering Information. This section covers data on PM materials that may be helpful to product design engineers and includes data for:

- Jominy hardenability
- Machinability
- Axial fatigue
- Rolling contact fatigue (RCF)
- Strain controlled low cycle fatigue
- Coefficient of thermal expansion (CTE)
- Fracture toughness
- Corrosion resistance
- Steam oxidation of ferrous PM materials
- Coefficient of friction
- Guidelines for specifying a PM part

These engineering data do not constitute specification values. The data in this section were developed through several different testing programs under the guidance of the MPIF Standards Committee or The Center for PM Technology (CPMT). The values should be used as guidelines, not minimum values or design values.

The MPPA Standards Committee is responsible for standard test methods for metal powders. These are also published in the book, MPIF Standard Test Methods for Metal Powders and Powder Metallurgy Products. The Committee comprises individuals from MPPA member companies. Standards that are developed by the Committee are subject to ballot by the six trade associations that comprise MPIF. The standards are reviewed on a periodic basis just like those under the jurisdiction of the MPIF Standards Committee.

Fig. 1 MPIF Standard 35, PM Structural Parts (Courtesy MPIF)

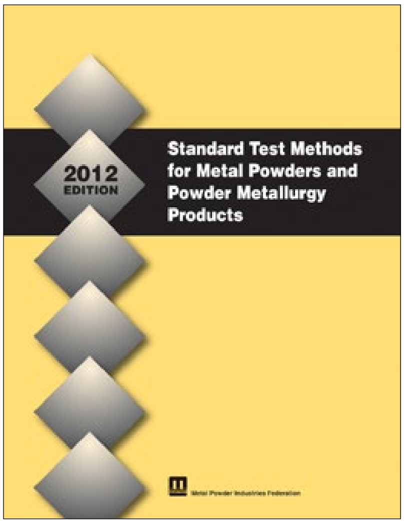

Fig. 2 Test methods are covered in MPIF's bumble bee book (Courtesy MPIF)

MPIF Standard 35
Materials Standards for PM Structural Parts
Materials Standards for PM Self-Lubricating Bearings
Materials Standards for P/F Steel Parts
Materials Standards for Metal Injection Molded Parts

Table 3 MPIF Standard 35 is probably the most widely used PM material standard in the world and comprises of four sub-categories

ISO/TC 119 Subcommittees		Secretariat
SC 2	Sampling and testing methods for powders (including powders for hardmetals)	SIS - Sweden
SC 3	Sampling and testing methods for sintered metal materials (excluding hardmetals)	DIN - Germany
SC 4	Sampling and testing methods for hardmetals	DIN - Germany
SC 5	Specifications for powder metallurgical material (excluding hardmetals)	ANSI / MPIF - USA

Table 4 There are four subcommittees of the ISO/TC 119

The MPPA Standards Committee also has the responsibility for the development of standard terminology for PM, MPIF Standard 09. In 2011 an agreement was reached with ASTM International for MPIF to reprint ASTM B243 and publish it as MPIF Standard 09. This agreement enables ASTM and MPIF to have the same definitions for terms used in Powder Metallurgy and represents a major milestone for the PM community in the USA.

The MIMA Standards Committee is responsible for the development and maintenance of MPIF Standard 35, Materials Standards for Metal Injection Molded Parts [8]. It is also responsible for some test method standards and for MPIF Standard 64 covering terms used in Metal Injection Moulding (MIM). Standards that are developed by the Committee are subject to ballot by the six trade associations that comprise MPIF. The standards are reviewed on a periodic basis just like those under the jurisdiction of the MPIF Standards Committee.

There is also an MPIF Standards Board comprised of a Chairman and the Chairmen of the MPIF Standards Committee, the MPPA Standards Committee, and the MIMA Standards Committee. Standards that are developed by the Committee are subject to ballot approval by the Corporate Affiliate members and the six trade associations that comprise MPIF.

European Powder Metallurgy Association (EPMA)

The European Powder Metallurgy Association is not directly involved in the development of standards, but has since its formation in 1990 been active in converting ISO PM standards into European Standards (EN) through the European Committee for Standardisation (CEN).

CEN itself does not develop standards but will adopt where necessary ISO standards. The reason for this activity by the EPMA was to remove national differences in PM standards and thereby eliminate technical barriers to trade within the European Union. A full list of current EN PM standards is published on the CEN website www.cen.eu. The EPMA was also responsible for developing a draft EN standard for Metal Injection Moulded materials.

"PM related standards for the International Standards Organisation (ISO) are the responsibility of Technical Committee (TC) 119"

International Standards Organisation (ISO)

PM related standards for the International Standards Organisation (ISO) are the responsibility of Technical Committee (TC) 119. As indicated previously, ISO/TC 119 was formally established in 1968 and the United States participation in the ISO PM standards development process is via ASTM Subcommittee B09.09 that has been given the TAG responsibility by ANSI. The Chairman of Subcommittee B09.09 appoints liaison consultants and they review ballot items and other requests from the various Subcommittees of ISO/TC 119 and develop a consensus response for the USA in accordance with ANSI guidelines. All United States responses are communicated via ANSI.

The secretariat of ISO/TC 119 is held by Sweden. ISO/TC 119 consists of four Subcommittees (Table 4).

The Committee is comprised of "P" and "O" members. The "P" members actively participate in the process of developing standards while "O" members are observers only. There are currently thirteen "P" members (Austria, Bulgaria, China, Germany, India, Japan, Republic of Korea (KATS), Romania, Russian Federation, Spain, Sweden, USA, United Kingdom) and seventeen "O" members (Croatia, Cuba, Czech Republic, Egypt, Finland, France, Greece, Hungary, Islamic Republic of Iran, Italy, Dem. P. Rep. of Korea (CSK), Poland, Serbia, Thailand, Tunisia, Turkey, Ukraine). Each country has a single vote and ballot items require a 66.66% acceptance by "P" members for approval. Each country develops its own position, generally through discussions within its own national standards development body.

Work items require an affirmative vote from five "P" members for acceptance and for the work to proceed. Working groups (WG) draft documents for review by the Subcommittee (CD) and once approved the documents are submitted for Committee ballot as Draft International Standards (DIS). The DIS voting period is three months, with a two month period being given for translation, prior to items being open for the three month DIS voting period. The document proceeds to an FDIS stage (Final Draft International Standard) after any substantive negatives have been resolved. The FDIS stage may be skipped under some circumstances, for example, 100% approval of the DIS and few, if any, comments.

Material standards: Identifying the material of choice

Material standards are intended to serve as a guide to initial selection of materials. A review of the performance characteristics of various materials in the standard permits the development of a short list of potential candidates for a given application.

MPIF Standard 35 was originally adopted in 1961. It had the title, "PM

Material Standards (Specifications)	MPIF	ASTM	ISO
Specification for Bronze-Base Powder Metallurgy (PM) Bearings (Oil Impregnated)	35	B438	
Specification for Iron-Base Powder Metallurgy (PM) Bearings (oil Impregnated)	35	B439	
Specification for Sintered Aluminum Structural Parts		B595	
Specification for Materials for Ferrous Powder Metallurgy (PM) Structural parts	35	B783	5755
Specification for Materials for Copper Base Powder Metallurgy (PM) Structural Parts	35	B823	
Specification for Powder Forged (PF) Ferrous Materials	35	B848	
Specification for Powder Metallurgy (PM) Boron Stainless Steel Structural Components		B853	
Specification for Metal Injection Molded (MIM) Ferrous Materials	35	B883	22068
Specification for Powder Metallurgy (PM) Titanium and Titanium Alloy Structural Components		B988	
Specification for Soft Magnetic Iron Parts Fabricated by Powder Metallurgy Techniques	35	A811	
Specification for Iron-Phosphorus Powder Metallurgy Parts for Soft Magnetic Applications	35	A839	
Specification for 50 Nickel-50 Iron Powder Metallurgy Soft Magnetic Parts	35	A904	

Table 5 Related MPIF, ASTM and ISO material standards specifications

Material Standards and Specifications" and contained a nomenclature system for designating the non-ferrous and the ferrous materials for which chemical composition limits and minimum density values were defined. In addition, typical tensile strength, apparent hardness, and impact energy values were listed.

In 1984 the PMPA Standards Committee, responsible for the development of the standard at the time, decided on a major change in the approach to the materials standard; it introduced the "guaranteed minimum value concept." Density was no longer a mandatory parameter. The material designation system replaced the letter suffix that had been used to indicate minimum density with a numerical suffix that indicated the minimum tensile strength of the material, the 0.2% offset yield strength for as-sintered materials and the ultimate tensile strength (UTS) for heat-treated PM materials. Density was included as one of the typical properties listed. Additional typical properties included yield strength, UTS, elongation, impact energy, transverse rupture strength, apparent hardness, and fatigue limit. The typical properties were listed for at least three densities. The MPIF standard has a section that uses inch-pound units and a separate section in which the SI equivalents are listed for the same materials. The material designation suffix for the listings in the SI section is the same as that used for the inch-pound section; there can only be one designation for each material.

Properties plotted as a function of density can be used to compare the performance of materials in order to develop a short-list of potential candidates for a given application. Fig. 3 illustrates the yield strength versus density for a number of admixed PM materials in the as-sintered condition while Fig. 4 indicates how the UTS of the same materials varies with density when the materials have been quench-hardened and tempered.

An important point to remember when reviewing a shortlist of possible materials for a given PM application is the hardenability of the individual materials. The cross-section of the various test specimens that are used to determine the mechanical properties of the materials are relatively small compared with those of many PM parts. While a given material may have the required performance characteristics, according to the data listed in the material standard, its hardenability

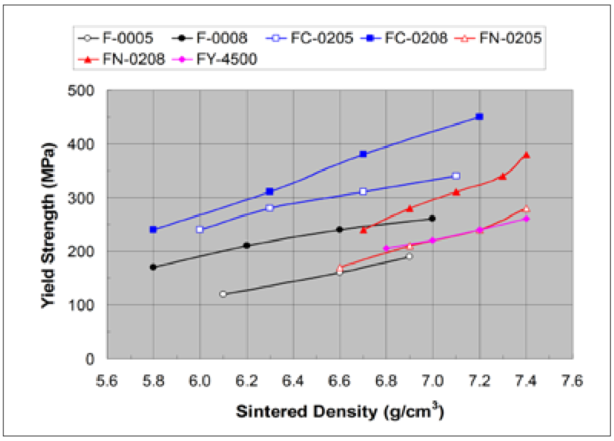

Fig. 3 As-sintered properties of some admixed ferrous PM materials

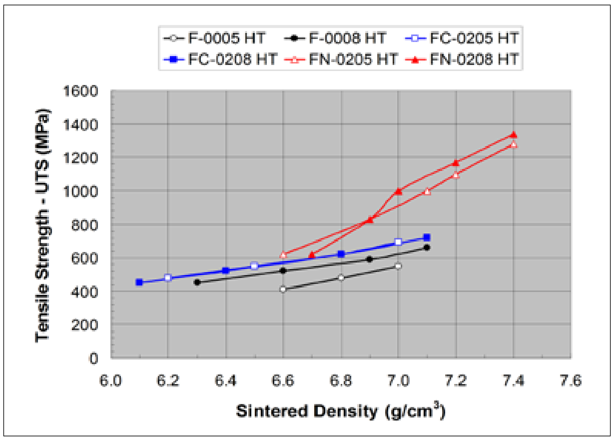

Fig. 4 Heat-treated properties of some admixed ferrous PM materials

Fig. 5 A recent meeting of the MIMA standards committee (Courtesy MPIF)

may be insufficient to develop the microstructure needed to develop those properties in the actual PM part.

Some additional factors need to be considered when comparing various materials. The material standard provides no information on the relative compressibility of the different materials. Nor are there data that indicate the dimensional change response of the materials or the sensitivity of dimensional change and the mechanical properties to changes in the chemical composition of the material (within the limits of the material specification). In order to make a material choice, the robustness of the material/processing needs to be considered and the cost of the full process sequence taken into account– not just the cost of the powder.

The ASTM standard that is equivalent to the *MPIF Standard 35, Materials Standards for PM Structural Parts* is B783 (Table 5). ASTM has adopted the same material designations as MPIF, and the property data for the various materials are the same. The ASTM standard is updated each time the MPIF standard is revised. There are separate ASTM standards for self-lubricating bearings; B438 and B439. These also have the same material designations and performance data as the MPIF Standard 35, Materials Standards for Self-Lubricating Bearings.

There is an ASTM standard for powder-forged (PF) materials, B848. There are no guaranteed minimum values for the powder-forged materials, just "typical" mechanical properties derived from laboratory prepared test specimens sintered and forged under commercial manufacturing conditions. It should be noted that the typical values include reduction of area data as the PF materials exhibit significantly better ductility than conventional pressed and sintered PM materials. The impact energy data for the PF materials are for notched Charpy test bars rather than the un-notched bars that are used for conventional PM materials.

The ISO equivalent to *MPIF Standard 35, Materials Standards for PM Structural Parts* and ASTM B783 is ISO 5755 [9]. This standard contains comparable data for most of the materials covered by the MPIF and ASTM standards. There are currently some materials that are not covered in the ISO standard. These will most likely be added in subsequent editions. The latest edition of ISO 5755 was published in 2012 and was a radical revision compared with the previous edition that was published in 2001.

While the ISO standard contains the same data for equivalent materials in the MPIF and ASTM standards, the material designation system used in the ISO standard is different. In addition to covering ferrous structural materials, ISO 5755 contains two tables that summarise the properties of materials that are used for self-lubricating bearings. Like the MPIF standard, the ISO standard has data for copper-based PM materials.

Data for metal injection moulded materials are contained in ASTM B883, which uses the same material designations and property data as MPIF Standard 35, Materials Standards for Metal Injection Molded Parts. In addition to guaranteed yield strength, the MIM standard also lists guaranteed UTS and tensile elongation values.

A new ISO standard for Metal Injection Moulded (MIM) materials was published in 2012 [10]. It is *ISO 22068, Sintered-Metal Injection Moulded materials – Specifications*. The new ISO MIM standard is currently at the approval stage at CEN and is expected to become a European Standard in April 2014. A three year project involving 34 industry and research partners in a 'Thematic Network on European Standards for Metal Injection Moulding' which was funded by the European Union's Brite EuRam programme and managed by the EPMA from 1997 to 2000 developed a draft MIM standard. This draft standard, in conjunction with the MPIF Standard 35 for Metal Injection Molded Parts, was used as a basis for the development of the new ISO Standard. The working group received significant input from the delegation from Japan to ISO/TC 119 SC 5 and spent time updating the MIM property data from the USA and Europe based on discussions with experts from those regions.

Standards for testing PM powders and products

The MPIF publication, *Standard Test Methods for Metal Powders and Powder Metallurgy Products*, contains standardised test methods for metal powders as well as standardised test methods for compacted and sintered materials that are used in PM parts. The latest edition of this publication was issued in 2012.

Tests for compacted and sintered PM materials include measuring the density, dimensional change, apparent hardness and microindentation hardness, tensile strength, compressive strength, impact energy, fatigue strength, radial crush strength, Jominy hardenability, and effective case depth (Table 6). There are also test methods for loss of mass in a reducing atmosphere (hydrogen loss), and for acid insoluble matter in iron and copper powders.

The test methods for metal powders include procedures for sampling, and tests for such properties as particle size, apparent density, tap density, flow rate, compressibility, and green strength (Table 7).As mentioned previously, MPIF Standard 09 lists a standard terminology of Powder Metallurgy and this is identical to ASTM B243 (Table 8).

The publication also contains standard tests for MIM materials such

Test Methods (Sintered PM Parts)	MPIF	ASTM	ISO
Tensile Properties of Powder Metallurgy (PM) Materials	10	E8	2740
Properties of Sintered Bronze Filter Powders	39		
Impact Energy of Unnotched Powder Metallurgy (PM) Test Specimens	40	E23	5754
Transverse Rupture Strength of Powder Metallurgy (PM) Materials	41	B528	3325
Density of Compacted or Sintered Powder Metallurgy (PM) Products	42	B962	2738
Apparent Hardness of Powder Metallurgy Products	43	E10, E18, E92	6506 6507-1 6508 4498
Dimensional Change from Die Size of Sintered Powder Metallurgy Specimens	44	B610	4492
Preparing and Evaluating Metal Injection Molded (MIM) Sintered/Heat Treated Tension Test Specimens	50		
Microindentation Hardness of Powder Metallurgy Materials	51	E384, B933	4498
Effective Case Depth of Ferrous Powder Metallurgy Products	52	B934	4507
Density of Impermeable Powder Metallurgy (PM) Materials	54	B311	3369
Radial Crush Strength (K) of Powder Metallurgy (PM) Test Specimens	55	B939	2739
Rotating Beam Fatigue Endurance Limit of Powder Metallurgy (PM) Materials	56		
Oil Content, Interconnected Porosity and Oil-Impregnation Efficiency of Sintered Powder Metallurgy (PM) Products	57	B963	2738
Surface Finish of Powder Metallurgy (PM) Products	58	B946	23519
Charpy Impact Energy of Unnotched Metal Injection Molded (MIM) Test Specimens	59	E23	5754
Preparation of Uniaxially Compacted Powder Metallurgy (PM) Test Specimens	60	B925	
Compressive Yield Strength of Powder Metallurgy Materials	61	E9	14317
Corrosion Resistance of MIM Grades of Stainless Steel Immersed in 2% Sulfuric Acid Solution	62		
Density Determination of Metal Injection Molded (MIM) Components (Gas Pycnometer)	63	D2638 D4892	
Determining he Percentage of Alloyed or Unalloyed Iron Contamination Present in Powder Forged (PF) Steel Materials		B795	
Nonmetallic Inclusion Content of Powders Intended for Powder Forging (PF) Applications		B796	13947
Surface Finger Oxide Penetration Depth and Presence of Oxide Networks in Powder Forged (PF) Steel Parts		B797	
Evaluating the Corrosion Resistance of Stainless Steel Powder Metallurgy (PM) Parts/Specimens By Immersion in a Sodium Chloride Solution		B895	
Metallographically Estimating the Observed Case Depth of Ferrous Powder Metallurgy (PM) Parts		B931	
Permeability of Powder Metallurgy (PM) Bearings Using Nitrogen Gas		B966	
Cleanliness of Powder Metallurgy (PM) Bearings and Structural Parts		B970	28279
Determination of Young's Modulus			3312
Sintered metal materials, excluding hardmetals - Fatigue test pieces			3928
Permeable sintered metal materials - Determination of bubble test pore size			4003
Permeable sintered metal materials - Determination of fluid permeability			4022
Metallic powders - Determination of oxygen content by reduction methods - Part 1: General guidelines			4491-1
Metallic powders - Determination of oxygen content by reduction methods - Part 3: Hydrogen reducible oxygen			4491-3
Metallic powders - Determination of oxygen content by reduction methods - Part 4: Total oxygen by reduction-extraction			4491-4

Table 6 Related MPIF, ASTM and ISO test method standards for sintered PM parts

Test Methods (Powders)	MPIF	ASTM	ISO
Sampling of Metal Powders	01	B215	3954
Loss of Mass in a Reducing Atmosphere for Metal Powders (Hydrogen Loss)	02	E159	4491-2
Flow Rate of Free-Flowing Metal Powders Using the Hall Apparatus	03	B213	4490
Apparent Density of Free-Flowing Metal Powders Using the Hall Apparatus	04	B212	3923-1
Sieve Analysis of Metal Powders	05	B214	4497
Acid Insoluble Matter in Iron and Copper Powders	06	E194	4496
Green Strength of Unsintered Compacted Powder Metallurgy Materials	15	B312	3995
Apparent Density of Non-Free Flowing Metal Powders Using the Carney Apparatus	28	B417	3923-1
Average Particle Size of Metal Powders Using the Fisher Subsieve Sizer	32	B330	
Compressibility of Metal Powders	45	B331	3927
Tap Density of Metal Powders	46	B527	3953
Apparent Density of Metal Powders Using the Arnold Meter	48	B703	
Copper Base Infiltrating Powders	49		14168
Measuring the Volume of the Apparent Density Cup Used with the Hall or Carney Apparatus	53	B873	
Apparent Density of Metal Powders and Compounds Using the Scott Volumeter		B329	3923-2
Particle Size Distribution of Metal Powders and Related Compounds by X-Ray Monitoring of Gravity Sedimentation		B761	10076
Particle Size Distribution of Metal Powders and Related Compounds by Light Scattering		B822	
Volumetric Flow Rate of Metal Powders Using the Arnold Meter and Hall Flowmeter Funnel		B855	
Metal Powder Specific Surface Area by Physical Adsorption		B922	
Metal Powder Skeletal Density by Helium or Nirtrogen Pycnometry		B923	
Flow Rate of Metal Powders Using the Carney Funnel		B964	
Metallic powders - Determination of envelope-specific surface area from measurements of the per-meability to air of a powder bed under steady state conditions			10070
Metallic powders - Determination of flowrate by means of a calibrated funnel (Gustavsson flowmeter)			13517
Lubricated metal-powder mixes - Determination of lubricant content - Soxhlet extraction method			13944
Metallic powders - Determination od apparent density and flow rate at elevated temperatures - Part 1: Determination of apparent density at elevated temperatures			18549-1
Metallic powders - Determination od apparent density and flow rate at elevated temperatures - Part 2: Determination of flow rate at elevated temperatures			18549-2

Table 7 Related MPIF, ASTM and ISO test method standards for powders

Miscellaneous	MPIF	ASTM	ISO
Standard Terminology of Powder Metallurgy	09	B243	3252
Terms for Metal Powder Compacting Presses & Tooling	31		
Terms Used in Metal Injection Moulding (MIM)	64	B243	
Sample Preparation for the Determination of the Total Carbon Content of Powder Metallurgy (PM) Materials (Excluding Cemented Carbides)	66		7625
Guide to Sample Preparation for the Chemical Analysis of the Metallic Elements in PM Materials	67		
Guide to Temperature Profiling a Continuous Mesh-Belt Sintering Furnace	68		
Guide to the Determination of Porosity in Powder Metallurgy products Using Automated Image Analysis	69		
Guide for Liquid Dispersion of Metal Powders and Related Compounds for Particle Size Analysis		B821	
Guide for Steam Treatment of Ferrous Powder Metallurgy (PM) Materials		B935	
Sintered metal materials, excluding hardmetals - Metallographic preparation and examination			14321

Table 8 Other related MPIF, ASTM and ISO standards

as tensile strength, impact energy, density, and corrosion resistance, along with a separate listing of terms used in Metal Injection Moulding.

There are guides for the preparation of samples for total carbon content, chemical analysis of the metallic elements in PM materials, temperature profiling a continuous mesh-belt sintering furnace, and for determining the porosity in PM products using automated image analysis.

MPIF Standard 31 lists terms for metal powder compacting presses and tooling. This is based on input from the Powder Metallurgy Equipment Association.

In most instances, there are comparable ASTM test method standards to those of MPIF (Tables 6 and 7) . Both groups work closely together and some of the same people are involved in the development of PM standards for both organisations. Any differences are generally a matter of form and style for the two groups.

Recent developments in standards for PM

Some of the recent developments with respect to MPIF standards include the new guides for the chemical analysis of the metallic elements in PM materials, temperature profiling a continuous mesh-belt sintering furnace, and for determining the porosity in PM products using automated image analysis. Data for strain controlled fatigue (low cycle fatigue) were added to the Engineering Information Section of the 2012 edition of MPIF Standard 35 and the Jominy data for selected materials were updated to reflect the use of more appropriate austenitizing temperatures.

A new ASTM material standard has just been published for PM titanium alloys (B988). This replaces B817, which has been balloted for withdrawal. The new standard covers a wider range of possible processing options for the various PM titanium alloys.

ASTM B330 has recently been updated to incorporate the use of the HEL sub-sieve autosizer (HEL SAS) as the Fisher sub-sieve sizer is no longer produced. A similar change will also be made to MPIF Standard 32 during its next revision.

Both ASTM and ISO have new standards for the cleanliness of PM parts (B970 and ISO 28279 respectively). Many PM parts, particularly those used in engine and transmission applications, have stringent requirements for cleanliness.

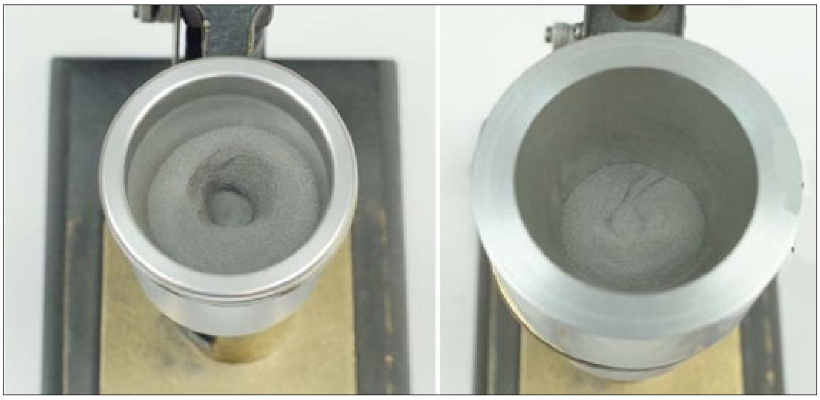

Fig. 6 Flow patterns in Hall Flowmeter (left) and the Gustavsson flowmeter (right) (From presentation by Mats Larsson, Höganäs AB, at Euro PM2012, Sweden)

A new flow measurement standard has been issued by ISO (ISO 13517). The new Gustavsson flowmeter funnel has a cone angle that is half that of the Hall flowmeter funnel (Fig. 6). Unfortunately, while the new funnel avoids the rat-hole effect, its precision, determined on the basis of a global interlaboratory study, is no better than that of the Hall funnel. It has been proposed that this funnel should be used for testing premixed powders while the Hall flowmeter funnel should be used for base metal powders. It is unlikely that this will happen, particularly in the USA, because when the "dynamic" method of MPIF Standard 03 and ASTM B213 is applied, the vast majority of premixes flow freely through the Hall flowmeter funnel.

Ongoing activities

The MPIF Standards Committee is developing data for the corrosion resistance of PM stainless steel materials that have been sintered under various conditions. A comparison is being made between the response of the materials to immersion in a 5% NaCl solution following ASTM B895 and salt spray testing per ASTM B117. The new data will be added to the Engineering Information section of *MPIF Standard 35, Materials Standards for PM Structural Parts.*

Information on the effect of a carburised case on the rotating beam fatigue response of PM materials is also being developed for inclusion in the Engineering Information section of MPIF Standard 35.

The Committee is revising MPIF Standard 10 in order to define the process steps for preparing machined tensile test bars more clearly. While flat, unmachined test bars are used for as-sintered PM materials, machined test bars are required for heat-treated materials; this includes sinter-hardened PM materials.

A working group of ISO/TC 119/SC 2 is aiming to establish a common understanding of the ejection characteristics of PM compacts. A workshop was held in Tokyo in 2012, during the ISO/TC 119 meetings, to review current methods for measuring ejection performance and to provide input to the working group assigned the task of developing a new standard related to this subject. Jesus Penafiel of Ames SA representing Spain is the convener of the working group (WG 15).

ISO standards for test methods now require a precision statement to help the user of the test understand the repeatability and reproducibility that can be anticipated from the test. ISO is somewhat behind ASTM and MPIF with respect to developing precision statements for its PM standards. A working group was organised and it developed a priority list for the development of precision statements for ISO/TC 119/SC 2 standards. The first test method for which a precision statement will be developed is *ISO 4490 Metallic powders – Determination of flow rate by means of a calibrated funnel (Hall flowmeter)* and a new working group (WG 18) has been established for this purpose.

Hot Isostatic Pressing (HIP) has been used to produce high performance PM parts. MPIF and the EPMA have both recently established activities related to HIP (the Isostatic Pressing Association of MPIF and European PM Hot Isostatic Processing Group (EPHG) at EPMA). There are currently two ASTM specifications for HIPed PM materials – A988/A988M and A989/A989M [11,12]. These standards are the responsibility of Committee A01 on Steel, Stainless Steel and Related Alloys.

Additive Manufacturing (AM) is currently a hot topic in technical circles and even in the general press. ASTM Committee F42 on Additive Manufacturing Technologies has five subcommittees with five approved standards and another twenty standards under development. One of their subcommittees is the US TAG to ISO TC 261. In Europe, there are more than twenty projects within the FP7 framework (EU funded) and the ISO standards organisation is now asking some technical committees if they see the need for standardisation or have the interest to perform work in this field.

Get involved!

Involvement in the PM standards development process is a great way to increase one's knowledge of powders and associated process technologies. Listening to and participating in the discussions related to proposed changes to a standard or the development of a new standard is a wonderful way to learn from the experts in the field.

PM standards are living documents and people who work in the industry and those that use the products of the industry have an opportunity to participate in their development. Contact someone at MPIF (if you are an employee of an MPIF member company), or someone at ASTM, or ISO to learn how you too can become involved in the standards development process.

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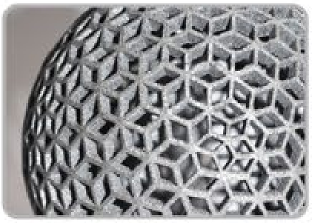

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Powder metallurgy is leading the way.

Euro PM2013 Gothenburg: High performance lubricants, heat treatments and crack detection

The Euro PM2013 Congress and Exhibition, organised by the European Powder Metallurgy Association (EPMA), took place in Gothenburg, Sweden, September 15-18, 2013. The event, which attracted over 700 participants, showcased the latest developments in Powder Metallurgy technology. Dr Georg Schlieper reports on three of the technical sessions that took place during the conference that focused on developments in high performance lubricants, heat and steam treatments and innovations in crack detection.

Spotlight on Powder Metallurgy lubricants

Lubricants for use in the production of Powder Metallurgy components is a subject that often receives less attention at PM conferences than other materials related areas. Nevertheless, particularly for manufacturing high performance PM components with increasing complexity, the proper choice of lubricant is important and significant progress has been made recently in the development of special lubricants for iron and steel powders.

Session 6 of Euro PM2013 was completely dedicated to innovative lubricants. Besides the traditional evaluation of apparent density, flow rate and compressibility, the ejection forces, part-to-part consistency and kinetics of the lubricant burn-off process were investigated. Lubricant developments were covered by presentations from leading iron and steel powder suppliers and Chalmers University of Technology.

Influence of delubrication process on the properties of sintered PM components

Seshendra Karamchedu, Chalmers University of Technology, Gothenburg, Sweden, investigated the lubricant burn-off of synthetic EBS wax from chromium containing PM steel powder compacts.

Since chromium in PM steels is particularly sensitive to oxidation, lubricant burn-off in an oxidising atmosphere must be avoided. The success of delubrication was measured by impact

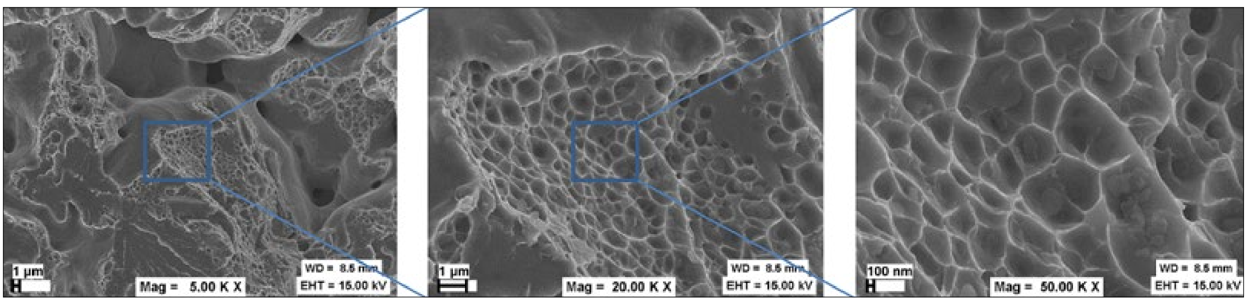


Fig. 1 Fracture surface of sample sintered after delubrication at 450 °C in dry N_2 [1] (Courtesy EPMA)

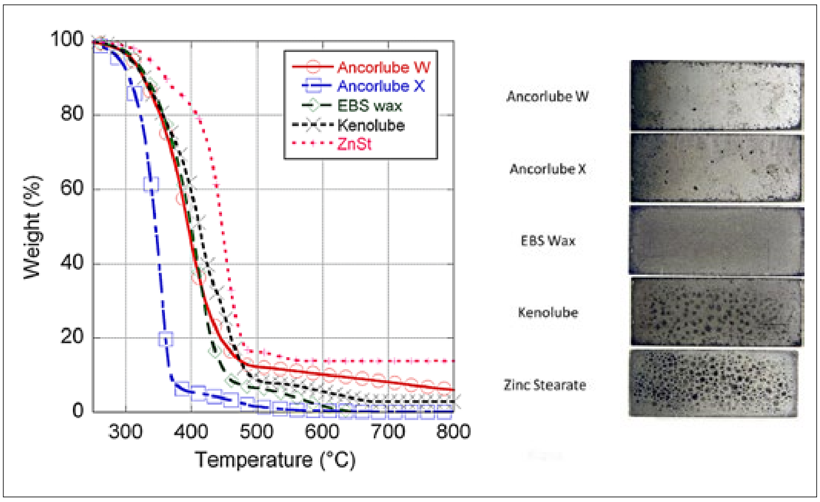


Fig. 2 Lubricant burn-off kinetics (TGA) and surface residues [2] (Courtesy EPMA)

testing, inspection of the fracture surfaces by SEM and EDX analysis of the oxygen content both after delubrication and after sintering. The best results were obtained after delubricating at 450°C in a dry nitrogen atmosphere and sintering at 1120°C in argon/10% hydrogen gas (Fig. 1).

Improved lubricant system for enhanced premix performance

Peter Sokolowski, Hoeganaes Corporation, compared the properties of innovative lubricants Ancorlube W, Ancorlube X, EBS wax and Kenolube. Without going into a detailed discussion of the results it can be said that iron base powder mixes with Ancorlube have similar powder handling characteristics to mixes with EBS wax and slight advantages in compressibility.

The ejection force (stripping force) at room temperature lies between those of EBS wax and Kenolube mixes, but, at 75°C, it is clearly lower than those for the two other mixes. Ancorlube X is reported to burn off at significantly lower temperatures than the other lubricants in the comparison and leaves a cleaner surface finish (Fig. 2).

Evaluation of innovative high performance lubricants for compaction of complex PM parts

Another innovative lubricant for iron and steel powders, the proprietary formulation PR-2, was introduced by Vincent Paris, Rio Tinto, Canada. PR-2 was compared with Acrawax C and Kenolube in mixes with iron powder ATOMET 1001, 2% Cu and 0.55% graphite. The authors investigated the amount of powder filled into a set of rectangular dies of diminishing width and found similar apparent densities, but the weight scatter was significantly less for the PR-2 mixes.

The authors concluded that the part-to-part consistency is better for components made with PR-2 lubricant and confirmed this with a compaction series of 100 cylindrical bushings with 25.4 mm diameter, 25.4 mm height and a wall thickness of 5.6 mm. Powder mixes with PR-2 again showed a clearly lower weight scatter than mixes with Acrawax C or Kenolube (Fig. 3).

Selection of lubricants and mixes for efficient production of high performance PM components

A comparison of newly developed Lube E with zinc stearate, amide wax, DM120 and BOOST lube in mixes with Astaloy 85 Mo + 0.5% graphite was presented by Mats Larsson, Höganäs AB, Sweden. The lubricant contents were varied between 0.5% and 1.0% by weight.

The bonded mixes Densmix 600 with DM120 for warm compaction, Starmix 500i with Lube E and Starmix BOOST with BOOST lube excelled in flow rate and apparent density.

Cylindrical samples of 25 mm diameter and 20 mm height were pressed on a hydraulic laboratory press to study the compressibility and lubrication. The highest compressibility at room temperature was achieved with zinc stearate. The ranking of lowest ejection energy was led by Densmix 600, Starmix 500i and Starmix BOOST. Further it was found that the weight scatter largely depends on the press rate and, if a critical press rate is exceeded, the weight scatter increases dramatically. Starmix BOOST and Intralube E mix allowed the highest press rates (Fig. 4).

Effect of lubricant particle size distribution on the processing and properties of PM ferrous parts

Yannig Thomas, National Research Council, Canada contributed a fundamental study on the effect of lubricant particle size. He investigated the com-

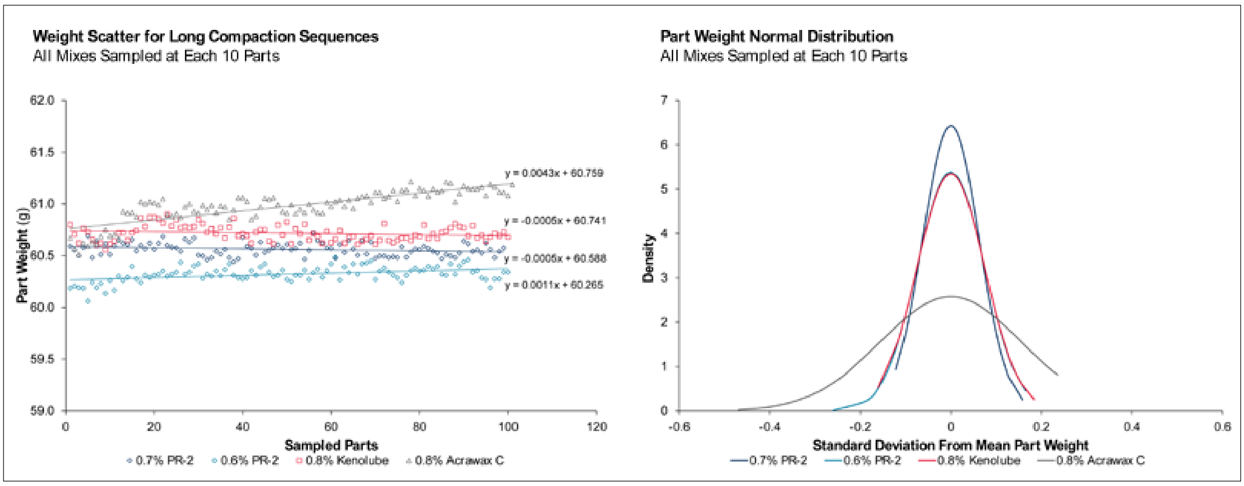


Fig. 3 Weight scatter of cylindrical bushings [3] (Courtesy EPMA)

pressibility and lubrication of mixes with ATOMET 1001HP + 1.8% Cu + 0,7% graphite with 0.7% EBS lubricant in cold compaction at room temperature and warm compaction in a die which was heated to 60°C. The average particle size D50 of the lubricant was varied between 2.5 µm and 25 µm.

The stripping shear stress was found to decrease by approximately 10% with increasing particle size, the lowest value being achieved with D50=25 µm. However, the compressibility with this lubricant particle size was approximately 0.05 g/cm³ less than with D50=15 µm. This was observed in cold compaction as well as in warm compaction. A lubricant particle size of D50=15 µm appeared to be the most suitable one.

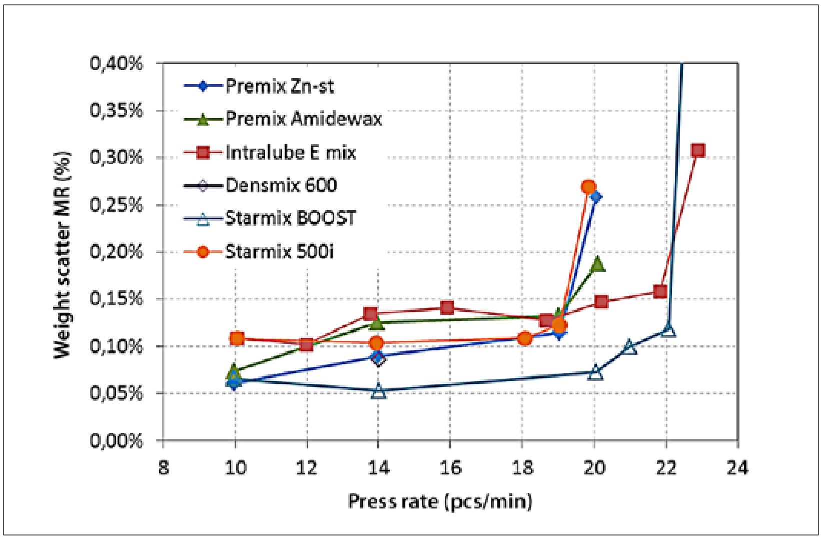


Fig. 4 Weight scatter as a function of press rate [4] (Courtesy EPMA)

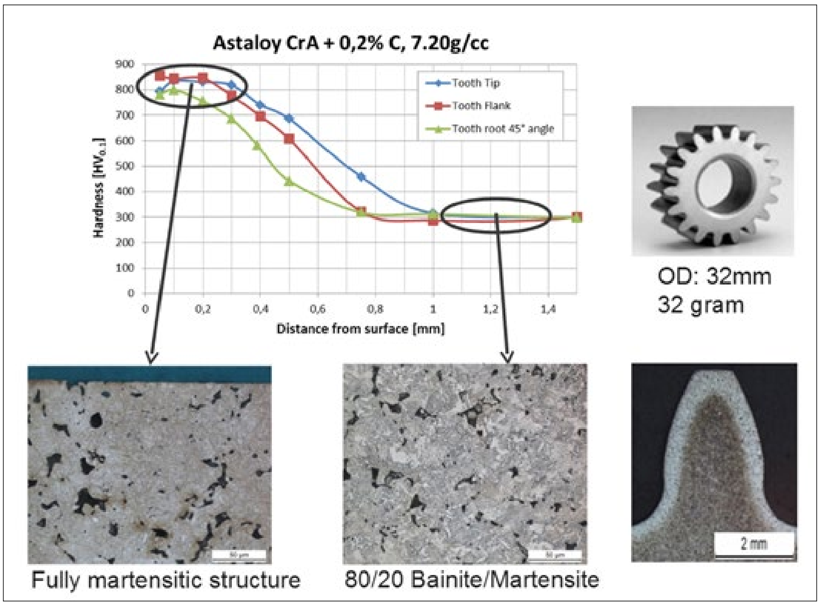


Fig. 5 Hardness profiles and microstructures of a case hardened PM gear [5] (Courtesy EPMA)

Heat treatment, steam treatment and advanced design

Heat treatment is always a major topic at Powder Metallurgy conferences since sintered components for applications under high loading usually require a heat treatment. Oral presentations at Euro PM2013 in Gothenburg covered innovative heat treatments that minimise dimensional change such as low pressure carburising and nitrocarburising. In these contributions the benefits of prealloyed steel powders containing chromium and/or molybdenum were prominent. A comprehensive overview of steam treatment, including a sophisticated experimental procedure and design options for better performance of PM gears, completed Session 17.

High performance PM components heat treated by low pressure carburising and gas quenching

Magnus Dahlström, Höganäs AB, Sweden, investigated the effects of low pressure carburising and subsequent high pressure gas quenching on the properties of prealloyed molybdenum and chromium containing low alloy PM steels. The outstanding benefit of this process over traditional gas carburising is that it is oxygen-free and therefore chromium steels can be carburised without oxidation.

The distortion caused by gas quenching is milder and therefore less than by oil quenching. However, this calls for the use of steels with a better hardenability than simple Fe-Cu alloys. Further, the process is regarded as more energy efficient, causing less CO2 emissions and avoiding the need for the cleaning of parts after case hardening.

Dahlström determined the microstructures and hardness profiles of PM steels based on Astaloy 85Mo, Astaloy CrA and Astaloy CrL powders and provided evidence of fully martensitic structures in the hardened zone and bainite/martensite structures in the core. An example is shown in Fig. 5.

Optimising tooth root design of PM gears for higher performance

Unique opportunities for PM technology in optimised gear design were demonstrated by Michael Andersson, Höganäs AB. While the shape of machined gears is limited by the evolving motion of the machining tool, dies for PM technology offers innovative design opportunities for gears that reduce local stresses in the tooth root.

Finite element analysis was used to determine the maximum stresses in the gear and then the radius of curvature in the tooth root was reduced and at the same time the material thickness was increased. Relatively minor modifications that are hardly visible with the naked eye were sufficient to reduce the maximum stresses by up to 30%. The author suggested that the optimisation of the tooth root geometry should be a routine step in PM gear design (Fig. 6).

EPMA President Philippe Gundermann provides an overview of the European PM industry

The EPMA's new President, Philippe Gundermann, CEO of Aubert et Duval, presented an upbeat view of the European Powder Metallurgy industry during his opening plenary presentation at Euro PM2013.

Gundermann began with an overview of the EPMA's activities, highlighting the work of the association's established sectorial groups and noting the creation of a new Additive Manufacturing group in response to the growth of this rapidly developing sector. Using the analogy of a tree with many branches, each representing a sector of PM, Gundermann stated that "the tree of PM technologies grows and grows."

The presentation continued with Gundermann identifying some of the key factors that make PM an attractive technology, especially in times when energy and raw material prices are forcing the use of more efficient processes with better material utilisation. As well as the savings in raw materials and energy consumption, PM offers lower costs due to savings in machining, welding and assembly, stated Gundermann, PM also offers shorter lead times and a freedom of design and material properties that are either impossible or very difficult via other processes, he added.

With some 82% of European PM parts production (by volume) identified as structural ferrous parts (Fig. 1), Gundermann also highlighted PM's strong relationship with the automotive industry. Production of passenger vehicles in Europe has fallen in recent years despite a gradual increase in new car registrations since 2010, he stated. Globally, however, the production of light vehicles is rising, strongly driven by the growing Chinese market.

Reflecting the fall in auto production in the region, Gundermann reported that the European shipments of ferrous powder for PM applications also fell in 2012 (Fig 2). It can be seen that copper powder figures, however, have been reported as fairly level for the last three years (2010-1012).

Hard material production was also reported as falling in 2012, according to figures from Kennametal and HC Starck (Fig. 3). In 2012 production was estimated at around 15,000 tonnes, lower than in 2011, but about equal to 2010 figures.

On a more positive note, Gundermann stated that Metal Injection Moulding (MIM) sales in Europe continued an upward climb and were reported at around €230 million in 2012, up from just over €200 million in 2011 (Fig. 4).

Gundermann also presented a very positive view of the Additive Manufacturing industry, highlighting a jump in growth since 2011. It is hoped that the establishment of the EPMA's Additive Manufacturing group will bring together companies involved in the metal sector of this technology from across the supply chain.

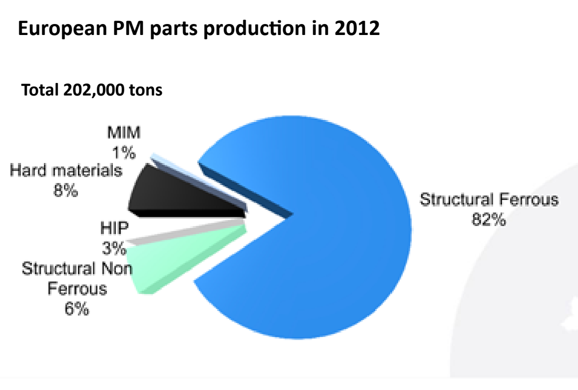


Fig. 1 Breakdown of PM parts production in Europe 2012 (As presented at Euro PM2013, Sweden)

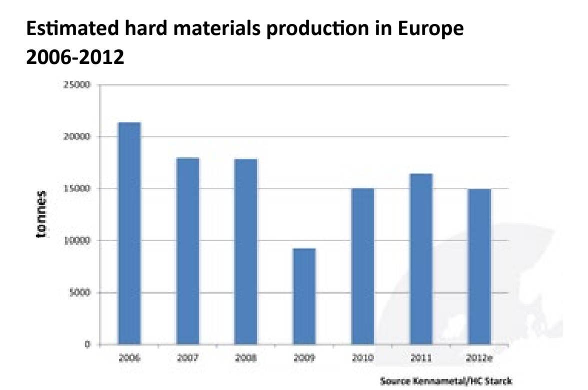


Fig. 3 European hard material production 2006-2012 (As presented at Euro PM2013, Sweden)

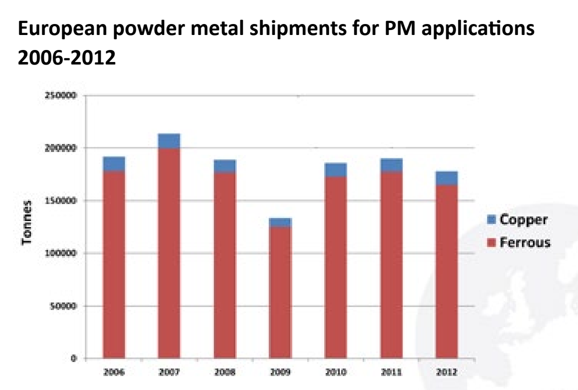


Fig. 2 European powder metal shipments for PM applications (As presented at Euro PM2013, Sweden)

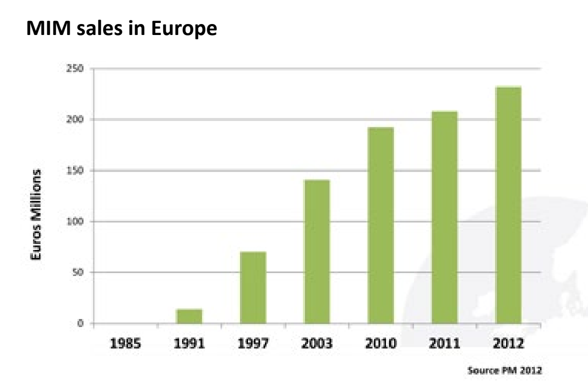


Fig. 4 MIM sales in Europe (As presented at Euro PM2013, Sweden)

Steam treatment of ferrous materials: influence of geometry, density, process conditions, on weight increases

Gian Filippo Bocchini, PM Consultant, Rapallo, Italy, gave a comprehensive overview of the effects of steam treatment on the mass gain depending on density, geometry and process conditions. In particular he investigated the local mass gain after steam treatment in a sophisticated experimental procedure. The local mass gain was determined on cylindrical steam treated samples by turning off thin slices on the outer diameter and the end faces.

The weight of the removed material in relation to the removed volume, i.e. the local density, was set in relation to the original density before steam treatment. In a plot of the mass gain versus the square-root of the distance from the surface for three different densities he found straight lines (Fig. 7) and thus demonstrated that for thick parts a square-root law holds.

Aspects of nitrocarburising of PM materials for improved wear resistance

Belt pulleys and the severe wear conditions in cars when driving on dusty roads were taken, by Caroline Larsson, Höganäs AB, as an example of the need for nitrocarburising heat treatment. A comparison was presented of a Fe-2% Cu-0.5% C alloy blend and prealloyed Astaloy CrA + 0.35% C both sintered at 1120°C/30 min in a 90% N_2/10% H_2 atmosphere. The best results were achieved with a steam treatment at 510°C/90 min followed by nitrocarburising at 580°C/100 min. (Fig. 8).

The wear properties of nitrocarburised surfaces of PM steels were evaluated with the dry sand-rubber wheel test according to ASTM G65. In this standardised test the sample is pressed against a rotating rubber wheel with a certain force and standardised sand pouring out of a hopper is the abrasive medium. The wear properties were compared in the as-sintered, steam treated and steam treated + nitrocarburised condition.

As expected, the chromium containing steel performed clearly better in the wear test since chromium forms hard nitrides in a well-defined compound layer and in the diffusion zone. A further improvement was achieved for the sample with MnS addition that also showed a higher C-content (Fig. 9).

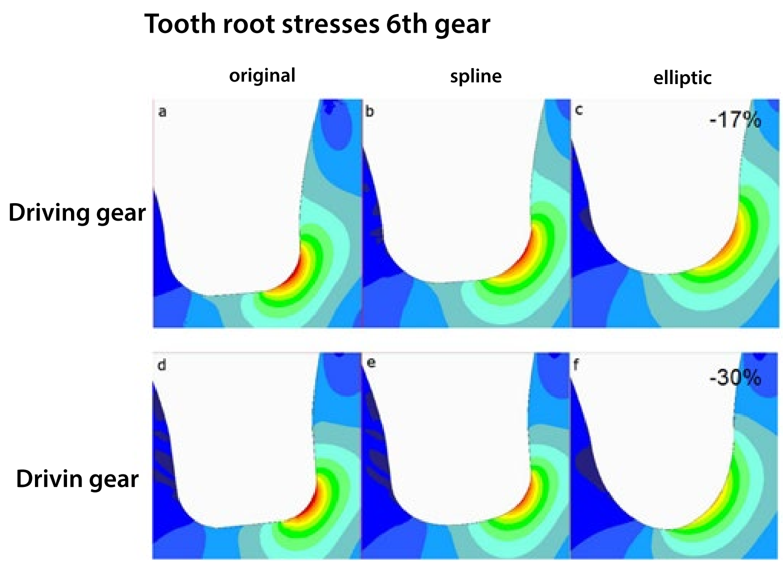


Fig. 6 Reduction of tooth root stresses by design modification [6] (Courtesy EPMA)

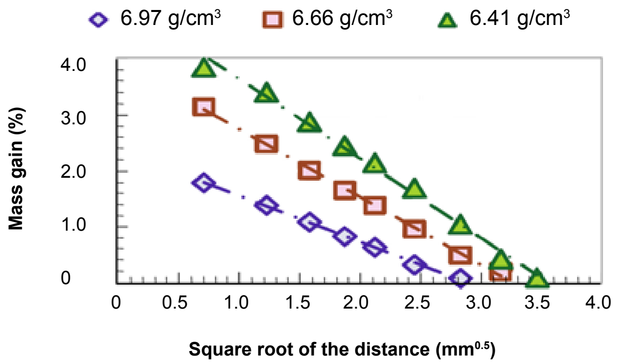
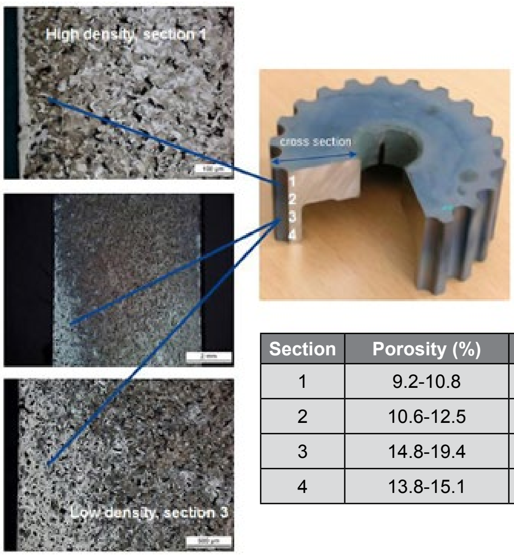


Fig. 7 Mass gain after steam treatment [7] (Courtesy EPMA)



Section	Porosity (%)	Est. density (g/cm³)
1	9.2-10.8	7.1
2	10.6-12.5	7.0
3	14.8-19.4	6.5
4	13.8-15.1	6.75

Fig 8 Steam treated and nitrocarburised part made of Astaloy CrA and the effect of large internal density variation [8] (Courtesy EPMA)

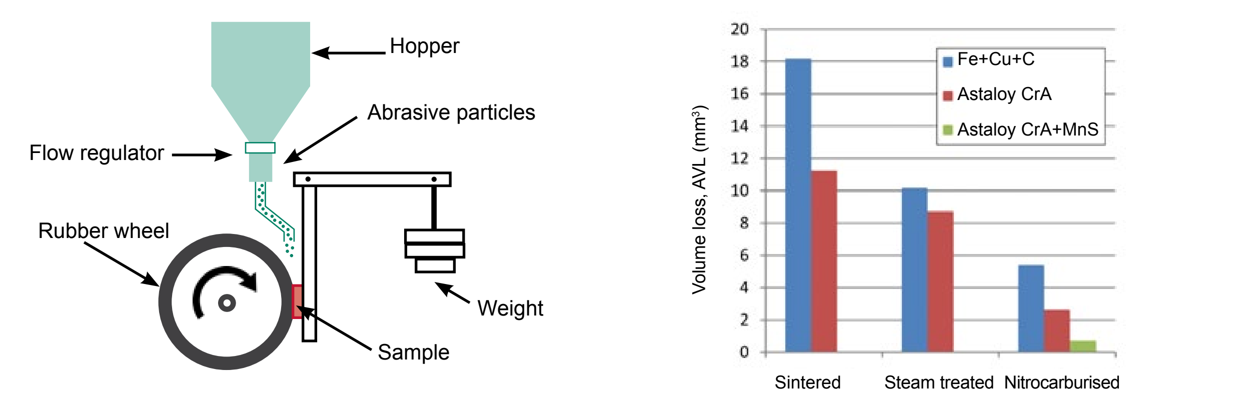


Fig. 9 Dry sand-rubber wheel test ASTM G65 and test results [8] (Courtesy EPMA)

Innovation in crack detection on green PM compacts

The inspection of green PM compacts for cracks and other defects is a problem that has caused concern for many powder metallurgists for a long time. However, with new developments in X-ray radiography, there now appears to be a realistic chance for fundamental progress in this field.

Prototype equipment for crack inspection by digital radiography is currently under development in two European research projects in the FP7 program, AutoInspect and DiraGreen. Results generated in the AutoInspect project were presented by three authors in session 27 at Euro PM2013. A fourth presentation covered the acoustic resonance method for inspecting sintered PM parts.

PM parts fast in-line X-ray digital radiography

Technical details of the AutoInspect system were presented by Mihai Iovea of Accent Pro 2000 Ltd., Bucharest, Romania. The AutoInspect system includes an X-ray source with a minifocus of 0.8 x 1.2 mm spot size. An integrated Al filter serves to eliminate the soft radiation. The radiation beam is screened by a collimator and, after passing through the inspected part, registered by a linear Time Delay Integration (TDI) detector. This detector produces a continuous scanning video image of the part that is moved through the X-ray beam at constant speed. A two-dimensional image is then computed out of a stack of linear arrays (Fig. 10).

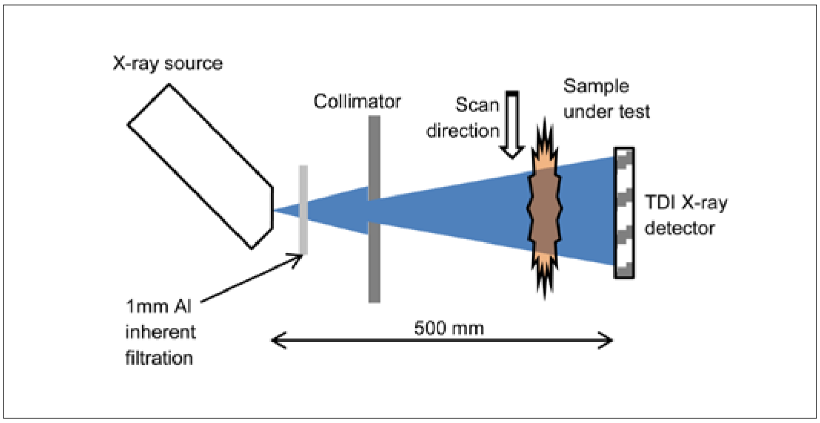


Fig. 10 Radiography setup used with the TDI linear X-ray detector [9] (Courtesy EPMA)

Production of ferrous PM parts for calibration and demonstration of typical defect detection performance of in-line X-ray digital radiography equipment

Christian Gierl-Mayer of the Technical University Vienna, Austria, presented a report on the preparation of samples with intentional density variations, cracks and defects for the calibration and demonstration of the capabilities of the new digital radiography equipment. Flat bars of constant thickness were pressed for calibration of the radiation intensity in correlation with the density. A linear correlation was found even without a correction for the sample thickness. (Fig. 11)

Several techniques were applied for creating internal defects, with coarse copper particles and pieces of copper wire being mixed into the powder and compacted. After sintering they left well-defined holes and cracks. Another method to produce defects was the simulation of cracks by inserting a foil into the die and the formation of cracks by double pressing and by pressing in a stepped die.

A defect detection and classification system for automatic analysis of digital radiography images of PM parts

The automatic detection of cracks and flaws on X-ray images can be dramatically improved with suitable image processing algorithms, as Maxim G Ponomarev of Brunel Innovation Centre in Uxbridge, UK pointed out. He explained that original X-ray images are often blurred and flaws or cracks are difficult to detect with the naked eye and even more difficult with automatic image analysis. Then he demonstrated the effects of various image processing techniques on digital radiographic images and impressively confirmed how a crack in a green MIM compact became recognisable that was virtually invisible in the original picture (Fig. 12).

Constant quality assessment by acoustic resonance testing

The current status of acoustic resonance testing (ART) was reported by Michael Weidner of Medav GmbH in Germany. The principle of the test method is that the natural vibration modes of sintered PM parts are excited by an electrically driven hammer or other means. Then the resulting sound signal is recorded by a microphone, transformed in the frequency spectrum and the resonance frequencies are analysed automatically by a suitable computer software.

Much attention has been given to the development of better statistical procedures for the automatic adaptation of the scatter band of tolerated deviations from the average value. The author assumed that modern high volume manufacturing processes run in a stable manner with the vast majority of products being within specifications and only occasional outliers occurred. He presented a concept and discussed why only this kind of evaluation could reliably monitor the process. The concept included an algorithm that automatically derives a minimum and maximum allowable scatter band. The tolerated scatter band follows continuously the gradual variations that may occur in a long running manufacturing process (Fig. 13).

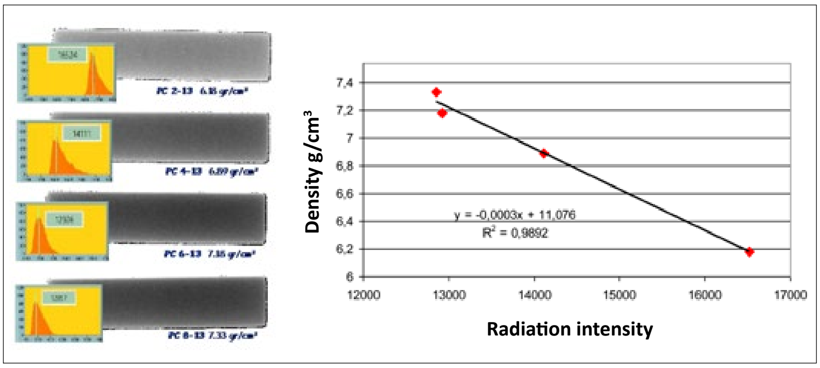


Fig. 11 Correlation of density and radiation intensity [10] (Courtesy EPMA)

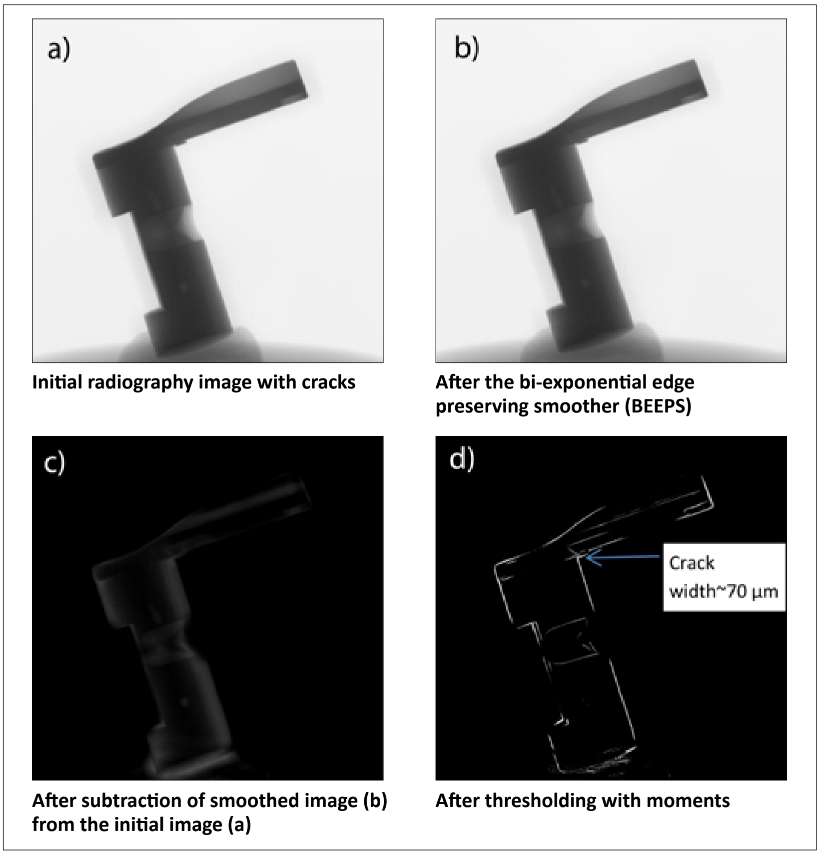


Fig. 12 Image processing techniques for crack detection in a green MIM part [11] (Courtesy EPMA)

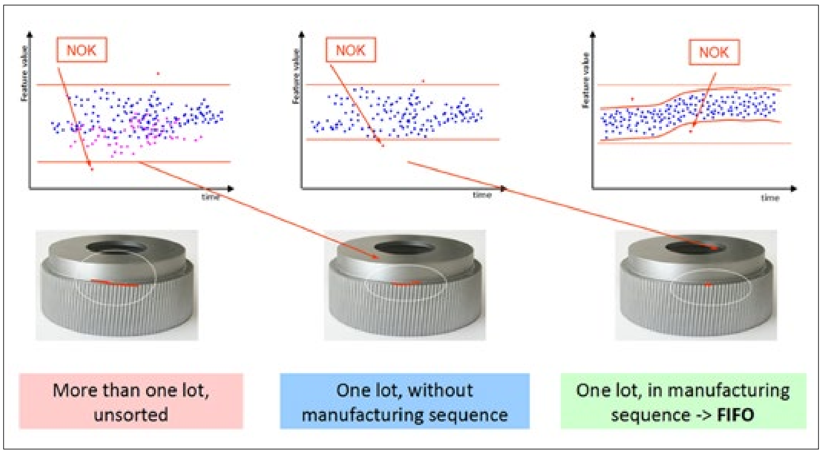


Fig. 13 Effectiveness of different statistical evaluation procedures [12] (Courtesy EPMA)

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[1] S Karamchedu, Influence of delubrication process on the properties of sintered PM components, as presented at Euro PM2013, Sweden

[2] P Sokolowski, Improved lubricant system for enhanced premix performance, as presented at Euro PM2013, Sweden

[3] Vincent Paris, Evaluation of innovative high performance lubricants for compaction of complex Powder Metallurgy parts, as presented at Euro PM2013, Sweden

[4] Mats Larsson, Selection of lubricants and mixes for efficient production of high performance PM components, as presented at Euro PM2013, Sweden

[5] Magnus Dahlström, High performance PM components heat treated by low pressure carburizing and gas quenching, as presented at Euro PM2013, Sweden

[6] Michael Andersson, The influence of notches on fatigue of heat treated sintered steel, as presented at Euro PM2013, Sweden

[7] Gian Filippo Bocchini, Steam treatment of ferrous materials: influence of geometry, density, process conditions, on weight in-creases, as presented at Euro PM2013, Sweden

[8] Caroline Larsson, Aspects of nitrocarburising of PM materials for improved wear resistance, as presented at Euro PM2013, Sweden

[9] Mihai Iovea, PM parts fast in-line X-ray digital radiography, as presented at Euro PM2013, Sweden

[10] Christian Gierl-Mayer, Production of ferrous PM-parts for calibration and demonstration of typical defect detection performance of in-line X-ray digital radiography equipment, as presented at Euro PM2013, Sweden

[11] Maxim G Ponomarev, A defect detection and classification system for automatic analysis of digital radiography images of Powder Metallurgy parts, as presented at Euro PM2013, Sweden

[12] Michael Weidner, Constant quality assessment by acoustic resonance testing, as presented at Euro PM2013, Sweden

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Euro PM2013 gallery

Japan's award winning Powder Metallurgy parts reflect an evolving automotive industry

The winners of the Japan Powder Metallurgy Association's (JPMA) 2013 Powder Metallurgy Awards once again demonstrate the continuing evolution of Japan's PM industry. The awards honour companies for the development of new materials, manufacturing processes and component design and evident in this year's awards are the increasing number of applications for PM in hybrid and electric vehicles.

Development Prize: New Design

Oil-impregnated sintered bearing for the motor of an idle speed control system

Diamet Corporation received an award for an oil-impregnated sintered bearing for the motor in an idle speed control system on small motorcycles (Fig. 1). The idle speed control system is widely used in medium to large motorcycles and four-wheeled vehicles. However in order to spread the application to smaller motorcycles a cost reduction and downsizing of the system was needed.

This resulted in the development of a heat resistant oil-impregnated sintered bearing which is able to be easily assembled, achieving a cost reduction through the net shape production process.

A newly developed Fe-Cu-Sn material offers low friction and the required strength. Two upper punches were used for sizing, with the sizing sequence optimised to achieve high accuracy of the products.

Diamet achieved both downsizing of the component and cost reduction in the production of the motor. The oil-impregnated sintered bearing for the motor of the idle speed control system of small motorcycles is now in mass production.

Joint for electric power steering motor

Diamet Corporation also received an award for a joint part which transmits movement from an electric power steering motor to a steering shaft (Fig. 2). In recent years, as joint parts with leg sections to improve torque transmission and assembly have

Fig. 1 Oil-impregnated sintered bearing for use in the motor of idle speed control system for small motorcycles (Courtesy JPMA)

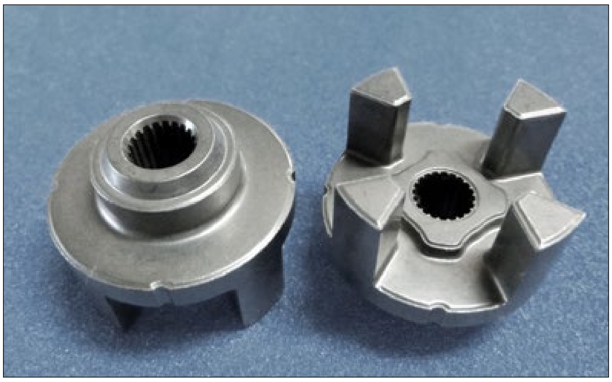

Fig. 2 Power steering joint component (Courtesy JPMA)

Fig. 3 Piston used in a motorcycle shock absorber (Courtesy JPMA)

Fig. 4 Sintered bearing for HEV and EV battery cooling fan motors (Courtesy JPMA)

increased in popularity, Powder Metallurgy has lost market share to forged alternatives.

The reasons for the reduction in PM's share was the low strength of the sintered leg sections and the cost to form them. In this component bending strength and hardness of the leg portions were improved through material selection, uniform density distribution and optimised heat-treatment conditions.

The combination of geometries of the lower punches was designed for uniform density distribution of the boss, enabling a 15% weight reduction by utilising the step formed with the lower punches to decrease thickness of the flange.

The scatter of the height of the leg portions was controlled by FEM analysis and optimisation of the production conditions, eliminating the need for machining of the tapered chamfers of the leg portions. As a result, mass production of the joint part was achieved, replacing forged alternatives.

Lightweight shock absorber piston for motorcycles

Fine Sinter Co., Ltd. won an award for a piston used in a motorcycle shock absorber (Fig. 3). The piston design has complex thin sections and internal structures.

The thinner portion is essential to ensure that the penetrating holes allow a receiving area for damping force characteristics of more than 65%. Challenges in the development of this new part related to product strength and mould strength, due to the thin sections and complex shape.

For the thin sections of the design Fine Sinter adjusted mould thickness by increasing and decreasing thickness in the part. Mould strength was achieved by selecting high strength and high toughness mould materials. Product strength was ensured by optimising the selected material.

As a result, the production of lightweight pistons with thinner sections was successfully achieved. Damping force characteristics were stabilised and the diameter of the shock absorber and spring lower loading were reduced, The development contributed to an overall cost reduction.

Sintered bearing for HEV and EV battery cooling fan motors

Porite Corporation won an award for an oil impregnated sintered bearing which is used in a battery cooling fan motor for hybrid electric vehicles and electric vehicles (Fig. 4).

Previously, ball bearings were used in brushless motors. However this new sintered bearing satisfies the requirements for lower noise and improved durability.

In this development, Porite adopted the "Nakanige" bearing, with close attention paid to the accuracy of tooling and the press, control of powder filling, density balances, and the optimisation of a repressing process. Through these improvements a 1 µm coaxiality between upper and lower sliding surfaces was achieved. Improvement of coaxiality makes the clearance between the bearing and shaft smaller, improving sliding performance and wear resistance and reducing clearance noise.

The motor that uses this new sintered bearing passed the necessary endurance tests at the customer, resulting in the conversion to a PM bearing from conventional ball bearings and offering cost reductions.

Reduced noise oil pump rotors

Diamet Corporation won an award for rotors for oil pumps driven by electric motors (Fig. 5). Conventionally, oil pumps for automobiles are driven by the engine so the noise they produce is masked by the noise of engine. With the spread of hybrid electric vehicles and vehicles with stop-start systems, the use of electric oil pumps is increasing. Because electric oil pumps are often used when engines are stopped, oil pump rotors are now required to offer both silent operation and high efficiency.

By focusing on the tooth gap between the inner rotor and the outer rotor, Diamet concluded that the low noise and high efficiency oil pump rotors previously developed generated a loud impact and vibration sound when the teeth engaged.

Based on this, the company developed a new tooth profile which reduced both tooth impact sound and vibrations. The rotors with the newly developed tooth profile exhibited a 25% noise reduction and 5% efficiency improvement compared with previously developed oil pump rotors.

Fig. 5 Reduced noise oil pump rotors for pumps driven by electric motors (Courtesy JPMA)

Fig. 7 Oil seal component used in the hydraulic chamber of a Variable Valve Timing system (Courtesy JPMA)

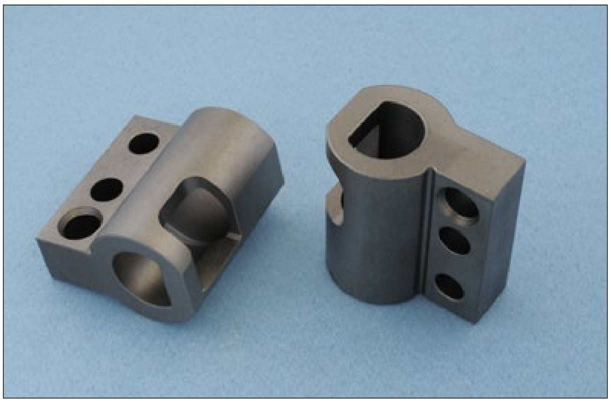

Fig. 6 Parking component for plug-in hybrid electric vehicle transmission (Courtesy JPMA)

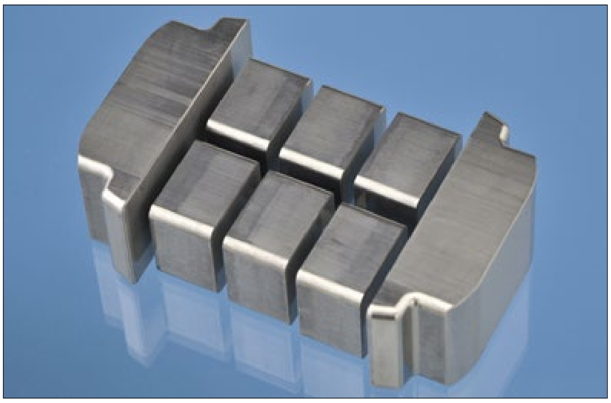

Fig. 8 SMC core used in the boost converter of the motor drive system in a Hybrid Electric Vehicle (Courtesy JPMA)

Parking component for PHEV transmission

Sumitomo Electric Industries, Ltd. won an award for a parking component used in the transmission developed for a PHEV (Plug-in Hybrid Electric Vehicle). The component locks the parking gear when the mating component slides on to the taper shaped part of this product (Fig. 6).

Since this component was as long as 50 mm in length and its shape required a lot of machining processes, the design was adapted to make it suitable for PM.

In this development, a density increase in the central length of the taper shaped part became a problem. To solve this, a low alloy Fe-Mo-Cu-C material was used, offering high-compressibility and high mechanical strength. The material was optimised and, along with appropriate lubricant, Sumitomo achieved the correct density rise and smooth ejection. The pressing process adopted a floating core and a dummy core, holding the upper side of the core from the upper punch side. The new component is now in mass production.

Development Prize: New Materials

Oil seal for VVT system

NTN Powder Metal Corporation won an award for a Powder Metallurgy oil seal component used in the hydraulic chamber of a Variable Valve Timing (VVT) system (Fig. 7). Characteristic demands of such oil seal parts are sealability, sliding and wear resistance. Resin was used traditionally, however the resin oil seal had lower dimensional accuracy and oil leaks at startup was a problem.

A PM oil seal offered higher dimensional accuracy than resin, however at the start of development there were problems relating to dimensional control. The use of graphite during sintering and a low sintering temperature Fe-Cu-Sn composition helped to resolve this issue.

The microstructure enabled improved accuracy through sizing, and free graphite working as solid lubricant offered excellent sliding characteristics. As a result, mass production of this sintered metal oil seal was achieved.

Process Development Prize

Low cost SMC core for an automotive reactor

Sumitomo Electric Industries, Ltd received an award for a Soft Magnetic Composite (SMC) core used in the boost converter of the motor drive system in a Hybrid Electric Vehicle (HEV) (Fig. 8).

Soft magnetic cores are smaller and lighter than conventional laminated steel cores, but to expand applications cost reduction is the most important factor.

In developing this part Sumitomo tried to achieve the required performance whilst lowering costs by using cheaper iron based powders, optimising the shape of product, improving the compacting method, and using a laser irradiation process.

The company was able to downsize by using pure and fine iron powders, but the eddy current loss created by the electric current on the component surface became a problem. To overcome this the compacting directions were adapted. In addition, the shape of

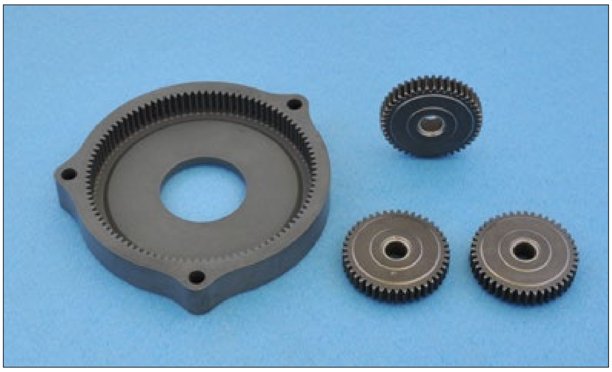

Fig. 9 Pinion and ring gear used in an automotive rear wheel suspension adjustment (Courtesy JPMA)

Fig. 10 Super thin oil-impregnated sintered bearing with hydrodynamic grooves on the bore (Courtesy JPMA)

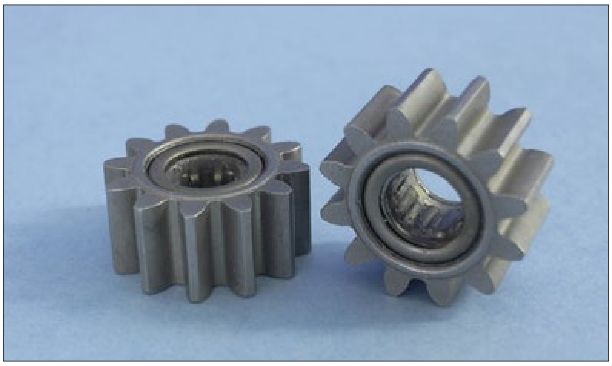

Fig. 11 Planetary gear used in the starter motor of an idling stop/start system (Courtesy JPMA)

the product was changed so that it could be compacted with a simple shoulder die, giving no interference with the reactor case.

In the middle core, a problem was that the eddy current travels around the outside of the component. This was overcome by shaping a non-conductive part by laser irradiation, intercepting the eddy current.

As a result, the company developed a pure iron based Soft Magnetic Composite core for an automotive reactor which had previously been made by laminated steel. Excellent performance was achieved as well as cost reductions.

Ring gear manufactured with a segregation-free mixed powder with excellent drilling performance

Sumitomo Electric Industries, Ltd. won an award for this pinion and ring gear used for the rear wheel suspension adjustment of a front-engined, front-wheel drive car. The component is used in the operation of an actuator (Fig. 9).

During pre-production, the specification as detailed in the drawings was achieved but operating noise inside the test vehicle failed to meet the target value. Thus, in order to obtain improved precision of the gear and tooth profile a die manufacturing optimisation process was carried out.

Extremely high mould accuracy and improved sintering methods resulted in effectively reducing operating noise.

As a result, it became possible to meet the target value for the operational noise of the actuator and mass production of the ring gear and pinion was achieved.

Effort Prize

Sintered hydrodynamic bearing for super thin fan motor

NTN Powder Metal Corporation received an award for this oil-impregnated sintered bearing which has hydrodynamic grooves on the bore (Fig. 10).

Mobile devices have become ever more popular and thinner cooling fan motors have had to be developed at a rapid rate. Demands for thinner bearings have therefore also increased. However, the size of the impeller (fan) to maintain cooling characteristics has tended to become larger and loads on the bearings have therefore increased.

To meet these demands, hydrodynamic groove specifications were optimised by improving the accuracy of the hydrodynamic bearing part width and expansion of groove angle, bearing clearance and hydrodynamic groove depth. Groove machining conditions were optimised with improved accuracy of the mould and optimisation of press operation. A lubricating oil able to maintain low evaporation and high rigidity was also developed.

As a result, the new thinner bearing has good oil film forming ability and non-contact support. Mass production of the sintered hydrodynamic bearing with low noise and high reliability for the super thin fan motor was achieved.

High strength planetary gear for stop/start systems

Hitachi Chemical Co., Ltd. won an award for a high strength and high dimensional accuracy planetary gear used in the starter motor of an idling stop/start system (Fig. 11).

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

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

Sintering conditions were optimised to reduce deformation during sintering and to increase the amount of nickel rich austenite phase in order to obtain high plastic deformation during the sizing of the inner diameter.

As a result, the dimensional accuracy of the newly developed material was improved by 60% and tensile strength was improved by 16% compared to the conventional 4% nickel material.

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

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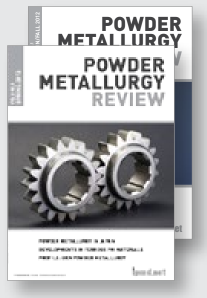

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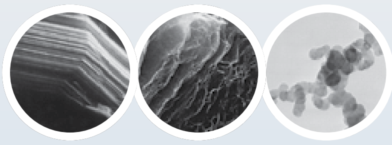

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