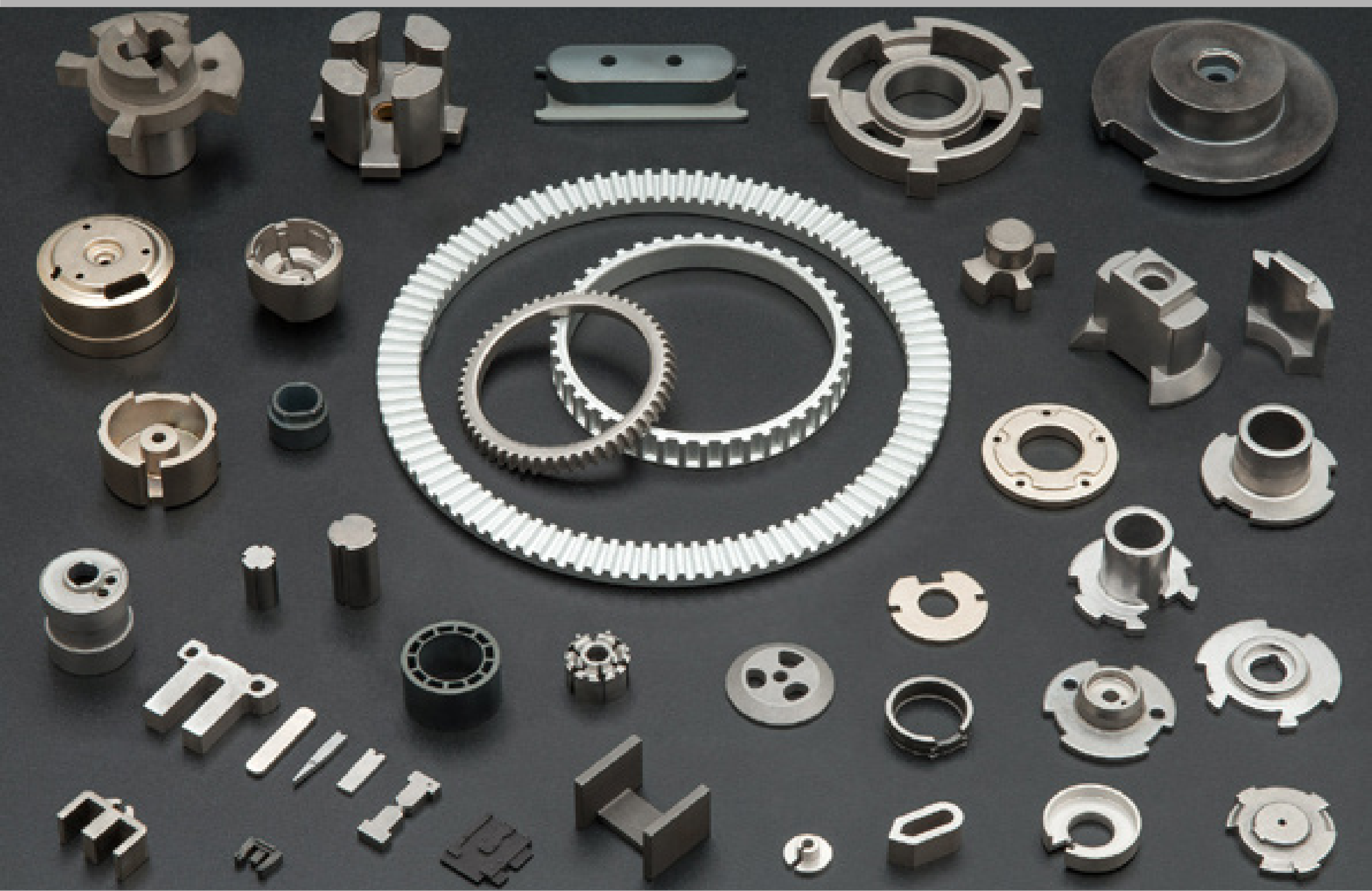
VOL. 4 NO. 3 AUTUMN/FALL 2015

POWDER METALLURGY REVIEW



PM SOFT MAGNETIC COMPONENTS
SINTERING TRAY MATERIALS
POWDERMET 2015

ipmd.net

Published by Inovar Communications Ltd

PEOPLE | FACILITIES | PRODUCTS

IMAGINATION *DRIVES* INNOVATION

THE FUTURE OF PM SOLUTIONS HAS ARRIVED!

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

Hoeganaes Corporation, the world's leader in the production of metal powders, has been the driving force behind the growth in the Powder Metallurgy industry for over 65 years. Hoeganaes has fueled that growth with successive waves of technology which have expanded the use of metal powders for a wide variety of applications.

Hoeganaes Corporation Innovation Center in Cinnaminson, NJ, USA. The site houses the Research and Development facilities for advanced engineered powders, such as AncorTech™ PM products and AncorAM™ powders for Additive Manufacturing.

The World Class Engineers and Scientists at Hoeganaes' new Innovation Center develop the new products and processes that move the state of the industry forward, spanning Automotive applications to Additive Manufacturing.

Our AncorTech products offer customers more efficient PM solutions with enhanced dynamic properties, higher densities, and greater design freedom.

With melting, atomizing and mixing facilities in North America, Europe, and Asia, Hoeganaes serves our customers across the globe with the most advanced PM solutions.

HOEGANAES CORPORATION
www.hoeganaes.com

MOBILE DEVICE APPS NOW AVAILABLE FOR DOWNLOAD

App Store | Google play

FOLLOW US ON SOCIAL MEDIA AT:

@HoeganaesCorp

YouTube LinkedIn

Publisher & editorial offices
Inovar Communications Ltd
2 The Rural Enterprise Centre
Battlefield Enterprise Park
Shrewsbury SY1 3FE
United Kingdom

Editor & Publishing Director
Paul Whittaker
Tel: +44 (0)1743 454992
Email: paul@inovar-communications.com

Managing Director
Nick Williams
Tel: +44 (0)1743 454991
Email: nick@inovar-communications.com

Consulting Editor
Dr David Whittaker
Consultant, Wolverhampton, UK

Production
Hugo Ribeiro, Production Manager
Tel: +44 (0)1743 454990
Email: hugo@inovar-communications.com

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.

Please contact Paul Whittaker, Editor
Tel: +44 (0)1743 454992
Email: paul@inovar-communications.com

Subscriptions
Powder Metallurgy Review is published on a quarterly basis. It is available as a free electronic publication or as a paid print subscription. The annual subscription charge is £85.00 including shipping.

Design and production
Inovar Communications Ltd.

ISSN 2050-9693 (Print edition)
ISSN 2050-9707 (Online edition)

ipmd.net

POWDER METALLURGY REVIEW

Opportunities for PM in the evolving automotive industry

"Resilience and creativity are the hallmarks of today's PM industry," MPIF President Richard Pfingstler told delegates during his state of the PM industry presentation at POWDERMET2015 in San Diego earlier this year. "Just as it has survived and thrived in the face of previous economic trials, these qualities will help insure that the industry will continue to grow in the face of challenges yet to come".

Despite a positive forecast for 2015, however, changes in the automotive sector could slow this growth. A move to smaller, lighter power units for example, will see a move away from the heavier PM parts. Of course, this move, along with the development of alternative fuel and electric power units, could also provide many new opportunities for the resilient and creative in our industry.

An example of new opportunities for growth can be seen in the soft magnetic components sector, where Powder Metallurgy is already a well established production process. Dr Mark J Dougan of AMES SA provides a detailed overview of the process and looks at the materials and applications (page 41).

Hot Isostatic Pressing continues to grow in significance for the processing of powder products. Dr David Whittaker reports on a number of key presentations from POWDERMET2015 that discuss a range of applications for the technology (page 73).

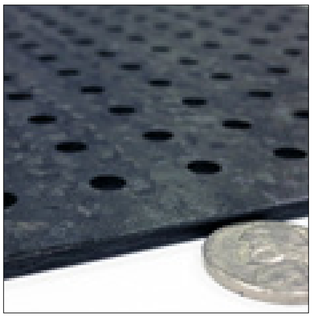
Paul Whittaker
Editor, Powder Metallurgy Review

Cover image
A selection of soft magnetic components manufactured by AMES (Courtesy AMES)

POWDER METALLURGY REVIEW

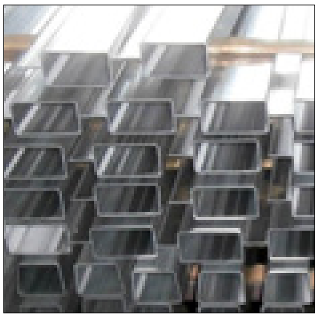
33

45



54

67



75

in this issue

regular features

industry news

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

Johnson Electric to buy Stackpole International

Johnson Electric Holdings Limited, a global leader in electric motors and motion subsystems headquartered in Hong Kong, has agreed to acquire the Stackpole International group of companies, a leading supplier of engine and transmission pumps and Powder Metallurgy components, in a transaction valued at C$800 million (US$608 million).

Stackpole, headquartered in Ontario, Canada, has a 109-year history as a supplier of highly-engineered components to the automotive industry and employs over 2,000 people globally. Its blue-chip customer base is comprised mainly of the world's leading automotive original equipment manufacturers and their Tier 1 suppliers.

"We identified pumps and highly-engineered components as strategic priorities for Johnson Electric to strengthen our position as a supplier to key engine and transmission applications that contribute to improved fuel economy and reduced emissions. Acquiring Stackpole's oil pump technology and powder metal expertise is an excellent fit that will enable us to provide integrated motorised pump solutions to customers in a rapidly growing market segment within the automotive industry," stated Dr Patrick Wang, Johnson Electric's Chairman and Chief Executive.

"In addition, the acquisition will significantly increase our exposure to the North American automotive market which is presently experiencing strong demand, as well as provide attractive longer term growth platforms in Europe and Asia," added Wang.

Since its carve-out from the Gates Corporation of Canada in 2011, Stackpole has been under private equity ownership and is presently owned by SI Investors, L.P., a limited partnership majority owned by Crestview Partners.

Stackpole's consolidated revenues for the year ended December 31, 2014 were C$487 million, excluding sales from its 30%-owned non-consolidated joint venture in Korea and China. Approximately 80% of its consolidated sales were made to customers based in North America. Stackpole's 2014 normalised earnings before interest, taxes, depreciation and amortisation (EBITDA) amounted to C$82 million, including a proportional share of EBITDA from its non-consolidated joint venture business.

Johnson Electric has agreed to acquire Stackpole in an all-cash transaction that values Stackpole at C$800 million on an enterprise value basis. In conjunction with the transaction, Stackpole's existing high-yield debt will be retired.

The transaction is expected to close in the fourth quarter of 2015, subject to customary conditions including obtaining applicable regulatory approvals.

www.johnsonelectric.com

www.stackpole.com

Berkshire Hathaway to acquire Precision Castparts Corp

The boards of directors of Berkshire Hathaway Inc. and Precision Castparts Corp. (PCC) have unanimously approved a definitive agreement for Berkshire Hathaway to acquire all outstanding PCC shares. The transaction is valued at approximately $37.2 billion including outstanding PCC net debt.

Precision Castparts Corp. is a worldwide manufacturer of complex metal components and products with $10 billion annual sales, which include powder production and isothermally forged PM superalloys and PM specialty steels. It serves the aerospace, power and general industrial markets.

"I've admired PCC's operation for a long time. For good reasons, it is the supplier of choice for the world's aerospace industry, one of the largest sources of American exports. Berkshire's Board of Directors is proud that PCC will be joining Berkshire," stated Warren E Buffett, Berkshire Hathaway Chairman and Chief Executive Officer. "We are very pleased to be joining forces with Berkshire Hathaway," added Mark Donegan, PCC's Chairman and Chief Executive Officer. "We see a unique alignment between Warren's management and investment philosophy and how we manage PCC for the long-term."

The transaction requires approval by a majority of PCC's outstanding shares. Closing is expected to occur during the first quarter of 2016, subject to customary closing conditions. PCC will continue to do business around the world under the Precision Castparts name and maintain its headquarters in Portland, USA.

www.precast.com

GKN to manufacture metal powder in China

In a brief statement on the website of its subsidiary, Hoeganaes Corporation, UK-based GKN plc has announced that its Powder Metallurgy division has agreed to form a joint venture with Bazhou Hongsheng Industrial Company Ltd., located in Bazhou City, Hebei Province, China. Bazhou Hongsheng Industrial Company was established in 2009 and is a leading provider of atomised iron and steel PM materials in China.

This new venture plans to manufacture international grade ferrous powders and will be the first international grade powder producer in China. A Chinese merger-control review application has been filed and other necessary approvals are being sought.

www.gkn.com/hoeganaes

Corporate management changes at Keystone

Keystone Powdered Metal Company, based in St. Marys, Pennsylvania, USA, has announced a number of changes to its corporate management team.

Michael G Stauffer has been appointed as Chief Operating Officer, a move from his existing role as Vice President of Sales and Marketing. In his new position, Stauffer will report directly to C J Kogovsek, Keystone's President and CEO, and will have overall responsibility for manufacturing, sales and marketing, research and engineering and human resources. The Vice Presidents of Operations, Sales and Marketing and Research and Engineering and the Director of Human Resources will now report Stauffer.

Michael A Werner, who was previously the company's Director of Purchasing & Supplier Relations, is now Vice President of Sales and Marketing. In this position, Werner will report to Stauffer and be responsible for all sales and marketing activities.

Dennis J Piccirillo was announced as Vice President of Corporate Quality Assurance, a move from Director of Corporate Quality Assurance. Piccirillo will report to Kogovsek and will have overall responsibility for quality assurance throughout the corporation.

www.keystonepm.com

New President and CEO at Sandvik

Sandvik has announced that Björn Rosengren will succeed Olof Faxander as President and CEO of the company on November 1, 2015. Faxander, who left the company on August 10, 2015, was appointed President and CEO of Sandvik in 2011.

"He [Faxander] has managed Sandvik through very challenging market conditions and made creditable contributions in the restructuring of Sandvik to a more efficient organisation," stated Johan Molin, Chairman of Sandvik. "The change of President and CEO was initiated by the Board and should be viewed as a next step in Sandvik's further development."

Björn Rosengren is currently the President and CEO of Wärtsilä Corporation. Prior to that, he held several management positions at Atlas Copco and has a strong background in other industrial companies, such as Nordhydraulic, Nordwin AB and ESAB Group. "I know Björn Rosengren as an exceptionally experienced and successful industrial leader. He has the experience needed to develop Sandvik into the future," added Molin.

Mats Backman, Executive Vice President and CFO, will be acting President and CEO in the interim period until Rosengren starts his new position at Sandvik.

www.sandvik.com

GKN Sinter Metals updates its St Marys facility

GKN Sinter Metals ribbon cutting ceremony

GKN Sinter Metals has officially unveiled its newly renovated facility in St Marys, PA, USA, following a ribbon-cutting ceremony. Among the guests were members of GKN's Powder Metallurgy leadership team, representatives of the state of Pennsylvania and a large group of the company's employees.

The construction project has taken over a year and consisted of various locations in the plant being renovated as well as a number of new additions.

In attendance were members of GKN's leadership team including the company's CEO, Nigel Stein. "I was very keen to see us raise the game and to continue to be the biggest powder metal company in the world," stated Stein. Also in attendance were Peter Oberparleiter, CEO GKN Powder Metallurgy; Abdul Butt, President GKN Sinter Metals; Wayne Meyer, VP Operations; Brian Durbin, VP of Strategy and Industrial Engineering; Brian Slusarick, Plant Manager - St Marys, and nearly 100 of its employees.

Stein went on to recognise the employees' efforts in learning and training which he believes empowers each and every employee. "That's what we really want in GKN; to let our employees give us their best, because when we do that we're incredibly successful," Stein said.

State Representative, Matt Gabler acknowledged the GKN leadership for their investment in the St Marys area and surrounding communities. "The workforce you have in front of you here is absolutely phenomenal. Not only are they good at their trade and putting world class products out into the market, but we also know they have hearts of gold," Gabler said. "They are committed to serving their community and making the world a better place." In the past twelve months Gabler recognised that the employees raised approximately $20,000 for charity and volunteered over 3,000 hours to their community.

St Marys was one of the many GKN plants to undergo this transformation known by the GKN Sinter Metals organisation as Project Phoenix. Each site involved in the process will undergo a face-lift of the offices and other areas to address future growth and improved facility layout, thus delivering a consistent look and feel throughout the region.

www.gknsintermetals.com

European Powder Metallurgy industry benefiting from continuing economic recovery

The European Powder Metallurgy industry is benefiting from the gradual economic recovery in Europe and, particularly, from a rejuvenated automotive industry over the past couple of years. Both ferrous and copper-based powder shipments to the PM industry were reported by the European Powder Metallurgy Association (EPMA) to have increased by 7.1% in 2014 compared with the previous year to 197,612 tonnes.

Ferrous PM powder shipments increased by 7.3% to 183,625 tonnes, whilst copper-base PM powder shipments showed a gain of 3.9% to 13,987 tonnes. The EPMA expects this growth trend to continue for 2015 with an anticipated 5% increase for PM powder shipments over the whole year.

The Metal Injection Moulding (MIM) sector is also reported by the EPMA to have put in another steady performance in 2014 gaining by around 10% by sales value to an estimated €280 million.

The Hot Isostatic Pressing (HIP) sector, where production is almost equally shared by HIPed stainless steel and HIPed tool steel/high-speed steels, has also reported growth despite the negative impact of the fall in oil prices on the energy/offshore sector, with total production in 2014 estimated at just over 14,000 tonnes. A potential market for HIPing is anticipated from the secondary compaction or densification of products manufactured by Additive Manufacturing (AM).

The EPMA reports that the European hard materials sector had a relatively tough year in 2014, with little change in production volumes due to declines in the construction and tooling sectors.

www.epma.com

HC Starck receives Boeing's Silver Performance Excellence Award

HC Starck has announced that its Fabricated Products Division has received the 2014 Boeing Performance Excellence Award. "We are thrilled to receive this award for the third year in a row from a leading-edge company like Boeing. HC Starck's proven ability to meet top customers' needs is critical in the increasingly competitive aerospace market," stated Dmitry Shashkov, Member of HC Starck's Executive Board and Head of the Fabricated Products Division.

"The long-term fundamentals in the aerospace sector are positive and represent concrete growth opportunities for us with our tungsten alloy balance weights for airplanes, helicopters, instrumentation and vibration dampening plus molybdenum alloy metal dies for forging fan blades and rotors," added Shashkov.

www.hcstarck.com

China sees growth slowdown in PM production but sales rise above $1 billion in 2014

According to figures issued by the China Machine Powder Metallurgy Association (CMPMA), production of structural PM parts in 2014 reached 193,238 metric tonnes, an increase of 7.2% over 2013 compared with growth of nearly 12% a year earlier. The figures are based on fifty responding PM structural part producers.
In terms of sales value, the CMPMA reports an increase of 6.9% for 2014 to Yuan 631,343 million ($1.017 billion), of which Yuan 143,686 million ($231.4 million) was attributed to new PM products – an increase of 80.4% over the previous year.

Exports of PM structural parts increased by 6.2% in 2014 to Yuan 64,367 million ($103.6 million). Total profits after taxes increased by 19.8% to Yuan 44,438 million ($71.56 million).

In the first quarter of 2015 the CMPMA reported that structural PM part sales increased by 20.2% to Yuan 170,095 million ($273.9 million), of which exports contributed Yuan 16,544 million, an increase of 22.1%. According to a market research report published earlier this year, production of high purity iron powder in China is estimated to have reached 498,000 tonnes in 2014. This includes both reduced and water atomised high purity iron powder including that used in the Powder Metallurgy sector.

China is outstripping all of the other Asian countries in PM production (see Fig. 1) thanks to its rapidly growing automotive sector. Only South Korea, which also has a sizeable automotive industry, has managed to see increased PM production along with Taiwan but at a much lower level than China. Asian PM part production, at over 400,000 tonnes in 2014, is now more than double that of Europe.

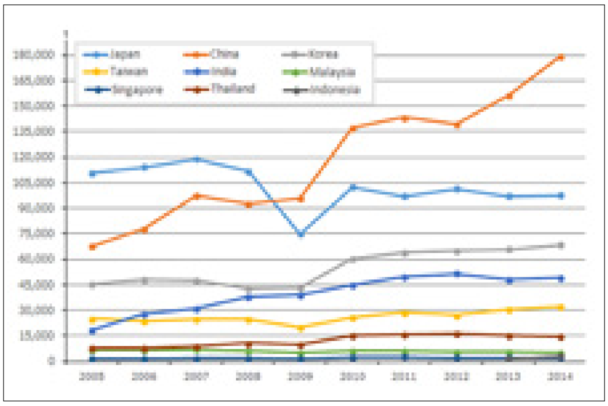


Fig. 1 PM production trends in Asia over the past 10 years (Source APMA)

Global car production and sales continue upswing in first half year

In the first half of 2015 global growth in the automotive sector was still supported by the three large automotive markets in Western Europe, North America and China. Car sales in Europe (EU28+EFTA) have increased by 8.2% to exceed 7.4 million with growth in nearly every region. However, the Russian car market continues to collapse with first half light vehicles sales down by 36% to 782,100 units.

Light vehicle sales in the US were up 4.4% in the first 6 months of 2015 to 8.485 million units whilst total light vehicle production increased by 2.7% to 5.956 million. Mexico continues to expand its production of cars and light vehicles with a half year increase of 8.6% to 1.723 million units, whilst Canada showed an 8.1% deterioration in production to 1.091 million. Total North American light vehicle production was up by 2.3% in the first half to 8.770 million.

The China Association of Automobile Manufacturers (CAAM) reports that production and sales of passenger cars reached 10.3 million and 10.09 million units respectively in the first six months of 2015, up 6.4% and 4.8% year-on-year. Continued growth has come from the increased demand for SUVs, which gained by 48%, and for MPVs, which enjoyed production growth of 16.4%.

In Japan new registrations of passenger cars fell by more than 12% in the first 6 months to 2.3 million units, whilst the Indian vehicle sales have risen by 5% to around 1.4 million units.

The Brazilian light vehicle market continues to go into reverse with January to June figures showing a 20% fall to 1.3 million units.

Federal-Mogul Powertrain acquires remaining TRW engine business

Federal-Mogul Powertrain has announced that it has purchased TRW's ownership shares in two engine components joint ventures, completing its acquisition of TRW's Engine Components business.

"We are pleased to complete the acquisition of TRW's engine components business which strengthens Federal-Mogul Powertrain's market position as a leading developer and supplier of core engine components," stated Rainer Jueckstock CEO, Federal-Mogul Powertrain and Co-CEO, Federal-Mogul Holdings Corp.

The acquired business, headquartered in Barsinghausen, Germany, employs nearly 4,000 people globally.

www.federalmogul.com

Höganäs to share knowledge in electric motor technology development

Sweden's Höganäs AB has announced a change in its strategy regarding electric motor applications, moving away from in-house product development to focus on providing technical support to customers developing their own systems.

"With the new business focus, customers will benefit more from our key competence and experience than before," stated Hans Söderberg, Director Electric Drive Systems at Höganäs. "We will not compete with other drive systems manufacturers, but support them in developing new and more efficient solutions."

Höganäs has many years' experience of developing soft magnetic powders, such as its Somaloy range, and the company will now help customers drive the development of new motor technologies. "The combination of our vast material know-how and experience from drive systems development is a perfect match. In Höganäs, customers will find a competent and reliable partner," added Söderberg.

Somaloy is the Soft Magnetic Composite (SMC) brand from Höganäs. The key concept is to produce components with 3D magnetic properties by pressing Somaloy powder to a desired shape. Somaloy materials are composed of surface-insulated iron powder particles, which in one single step can be compacted to form components with complex shapes and tight tolerances.

www.hoganas.com

MPIF announces winner of 2015 Howard I Sanderow Award

The Metal Powder Industries Federation (MPIF) has reported that its Technical Board has selected a paper by Stephanie Choquette and Iver E Anderson, FAPMI, Ames Laboratory (USDOE)/Iowa State University, as the recipient of the 2015 MPIF Howard I. Sanderow Outstanding Technical Paper Award.

The paper, Liquid-Phase Diffusion Bonding: Temperature Effects and Solute Redistribution in High Temperature Lead-Free Composite Solders, was one of 32 qualified manuscripts presented at the POWDERMET2015 conference in San Diego, California, USA, that were critically evaluated for the prestigious award.

The authors will receive their award plaques during POWDERMET2016, June 5 - 8, in Boston, Massachusetts, USA. The paper is published in the MPIF's CD-ROM conference proceedings, Advances in Powder Metallurgy & Particulate Materials - 2015.

www.mpif.org

ASCO Sintering opens new sales and engineering office in UK to focus on European market

ASCO Sintering, based in California, USA, has announced the opening of a new UK sales and engineering office to service its European customers. The new office will be headed by ASCO's European Sales Manager, Paul Edwards, and offers the company's advanced Powder Metallurgy sintering solutions to European companies.

ASCO specialises in custom complex, multi-level and miniature products from high quality Powder Metallurgy materials that, when required, it states, are capable of the hardness and tensile strength properties of a raw metal or alloy. The company is ISO 9001: 2008 certified and parts conform to CE and ATEX standards.

The new sales office will allow ASCO, which manufacturers in the USA, to effectively sell and service clients in Europe. Edwards believes that custom PM parts produced in the USA can offer substantial cost savings compared to CNC machining or MIM solutions in applications such as medical, automotive, industrial machinery, military components and firearms.

www.ascosintering.com

Makin Metal Powders appoints new East Asia Sales Manager

Makin Metal Powders, Rochdale UK, has announced that Michael Yan has been appointed East Asia Sales Manager and will represent the company's interests in China, Korea and Japan. Yan will take on this new position as well as retaining his existing role as the Export Sales Manager at Makin's parent company GRIPM, based in China.

Yan, who has directed the International Business unit at GRIPM since 2013, previously worked in the role of international sales manager for GRINM (Beijing General Research Institute for Nonferrous Metals) for 10 years. He covers a number of varied industry sectors of nonferrous metals including rare earth materials, magnesium alloys, aluminium alloys, optical coating materials, refractory metals, etc.

Yan is a graduate in metallurgical technology with a Master of Business Administration degree and has a deep understanding of metal powder products and the technical challenges customers are seeking to overcome. Though based in China, Yan spends considerable time at the Makin plant in the UK, working with the development and production teams as well as becoming familiar with the plant.

www.makin-metals.com

Expansion at Atomising Systems

Atomising Systems Ltd, Sheffield, UK, has reported that it has expanded its workforce to cope with a major influx of orders for metal powder. Staff numbers at its Darnall facility have increased from 35 in September 2014 to over 60 in June 2015 to allow the company's two 500 kW melting furnaces to operate at maximum output.

The company, which as well as manufacturing metal powders is a major supplier of equipment for the atomisation of metals, has taken on four new apprentices to join several that were hired two years ago and who are now finishing their training.

As well as hiring enough staff to operate the existing plant at maximum output, ASL is investing heavily in new equipment. A £100,000 major upgrade of the gas atomiser is in hand, while a large new sieving station of similar cost has just been put into production on special steel grades.

Further investments include a new instrument using laser diffraction to measure particle sizes as fine as one micron and the QC laboratory is being expanded with the addition of an oxygen analysing system.

Simon Dunkley, who took over management of the company from his father, Dr John Dunkley, in 2010, stated, "After some tough times, it is very gratifying to see our investment in plant and research at last paying dividends. It is particularly pleasing to be able to offer so many young people the opportunity to work in a leading-edge technical environment that allows so much scope for them to develop their talents. Our recent investments should further allow us to fulfil the exacting demands of leading metal powder users around the world."

The company's new apprentices with Simon Dunkley (centre). Left to right: Ashley Coe, Steven Parker, Natalie Galt and Ben Twomey

www.atomising.co.uk

Summer 2015 issue of Metal AM magazine now available to download

Available in both print (ISSN 2057-3014) and digital (ISSN 2055-7183) formats, *Metal Additive Manufacturing* magazine brings together industry news and articles on technical and commercial developments in the industry. In addition to a comprehensive 31 page industry news section, this 72 page issue includes the following articles and reports:

- Additive Industries: Moving towards automation and integration in metal Additive Manufacturing
- Advances in aerospace applications: MTU produces Airbus A320neo borescope bosses with Additive Manufacturing
- AMPM2015 conference report: Innovative materials, powder characterisation and metallographic testing
- Rapid.Tech 2015: Germany's conference and exhibition on AM targets an international audience
- Concept Laser's QMmeltpool 3D: In-situ quality assurance with real-time monitoring down to the micron level.

A free digital issue in PDF format is available to download from *Metal Additive Manufacturing* magazine's website.

www.metal-am.com

Concentric announces restructuring plan in Argentina

Concentric AB, which acquired GKN Sinter Metals de Argentina SA (GKN Pumps) earlier this year, has announced plans for the restructuring of the facility in Chivilcoy, Argentina, due to the weak demand in the South American commercial vehicle market.

The company has stated that it anticipates a headcount reduction of 34 employees that were engaged at the date of acquisition. Part of the headcount reduction has already been delivered and the remainder will be delivered through a mix of voluntary and compulsory redundancies. It was stated that the move will help bring Concentric Chivilcoy's margins in line with the rest of the group. The redundancy programme will result in annual savings estimated at MSEK 9. Concentric stated that the total one-off expenses recognised for the restructuring plan at the renamed Concentric Chivilcoy plant amount to MSEK 14.

"As noted in our Q1 2015 interim report, Concentric has recognised MSEK 15 of income arising from negative goodwill as the fair value of the net assets acquired with GKN Pumps exceeded the purchase price. Historically, GKN Pumps has been an unprofitable venture and, as a result, the seller approached Concentric intent upon a strategic exit from the pump manufacturing business. This, together with the apparent over manning in the Chivilcoy facility at the date of acquisition, enabled Concentric to agree a favourable purchase price."

With the acquisition of GKN Sinter Metals de Argentina SA, Concentric gained an important foothold in the Mercosur trade union, thereby enabling further penetration of the South American commercial vehicle market.

www.concentricab.com

India's SRPM begins metal powder production

Shree Rajeshwaranand Paper Mills Ltd (SRPM), located in Gujarat, India, has announced a move into metal powder production. In addition to being one of India's leading paper products manufacturers, the company has diversified into manufacturing resin bond, ceramic bond and metal bond grinding wheels and a range of metal powders.

SRPM announced that it has established a state of the art manufacturing plant. The company began production in March 2015 and offers special grades of prealloyed powders suitable for Metal Injection Moulding (MIM), Diamond Tools and other PM applications. The range also includes cobalt, tungsten, iron and nickel metal powders.

shreerajeshwaranandgroup.com

Bodycote's Jane LaGoy receives ASTM Award

Jane LaGoy, Technical Services Manager at Bodycote in Andover, Massachusetts, USA, has received the 2015 ASTM International President's Leadership Award in recognition of her work for ASTM's Metal Powders Committee.

LaGoy, who joined ASTM in 2010, is a very active member of Committee B09 on Metal Powders and Metal Powder Products. She currently serves as B09 secretary and chairs Subcommittee B09.05 on Structural Parts. She has been instrumental in the development of and revisions to several key ASTM standards for the Powder Metallurgy industry during her short tenure.

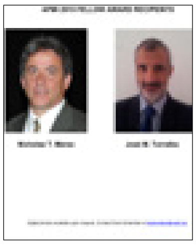
LaGoy is a member of the American Foundry Society, APMI International, ASM International, and serves on the technical board of the MPIF.

www.astm.org

Nicholas T Mares and José M Torralba named as 2015 APMI Fellows

Nicholas T Mares, Vice President of Marketing, Asbury Graphite Mills, Inc., and Professor José M Torralba, Universidad Carlos III de Madrid, have been named 2015 APMI Fellows. Established in 1998, the Fellow Award recognises APMI members for their significant contributions to the society and high level of expertise in the technology of Powder Metallurgy, practice, or business of the PM industry.

Mares has almost 35 years in the PM industry. He received his BS in Business: Management & Marketing from the University of Detroit, Mercy. Although his educational training is in business, he has worked diligently with the industry to refine its needs for graphite, nanographite, and coatings for carbon trays. Mares is a past-president of APMI, former director of the Metal Powder Producers Association.



Nicholas T Mares (left) and José M Torralba (right) have been named APMI Fellows

Torralba is considered one of the leading experts in the European PM field. He has graduated over 20 PhD students, and currently leads a research group of 28. Torralba has been a member of APMI for nearly 20 of his 30+ year professional career.

Torralba has published over 350 conference technical papers, 200 science papers on the web, and has eight patents.

www.mpif.org/apmi

Magna to acquire automotive transmission maker Getrag

Magna International Inc has announced that it has signed an agreement to acquire the Getrag Group of Companies, one of the world's largest suppliers of automotive transmissions. The purchase price for 100% of the equity of Getrag was stated as being around €1.75 billion.

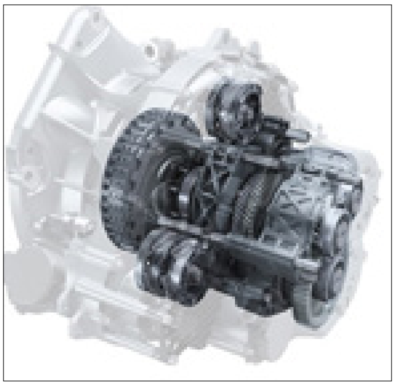
Getrag has an 80-year history in transmissions and offers a range of transmission systems, which includes manual, automated-manual, dual-clutch, hybrid and other advanced systems.

In addition to its wholly-owned operations, Getrag has significant joint-venture relationships with Ford, as well as Chinese auto makers Jiangling and Dongfeng. Other Getrag customers include BMW, Daimler, Renault, Volvo and Great Wall.

Including joint-venture locations, Getrag has approximately 13,500 employees and operates 13 manufacturing and ten engineering centres in nine countries in Europe, Asia and North America. Getrag's 2014 consolidated sales were approximately €1.7 billion, which excludes approximately €1.6 billion in sales generated in its non-consolidated joint-ventures.

"As part of our ongoing product portfolio review, we have identified the expansion of our powertrain business as a strategic priority. Getrag is an excellent fit with this strategy," stated Don Walker, Magna's Chief Executive Officer.

"Getrag is a technology leader in a product area that we believe is well-positioned to benefit from industry trends that are driving increased vehicle fuel-efficiency and reduced emissions. Getrag's joint venture relationships also provide significant growth potential in China, the world's largest automotive market and the fastest growing market for DCTs. Lastly, Getrag has a highly capable and experienced workforce, including deep powertrain engineering expertise," added Walker.



Getrag is one of the world's largest suppliers of automotive transmissions systems

The transaction is expected to close near the end of 2015, subject to a number of conditions including obtaining all necessary regulatory approvals.

www.magna.com

Last chance filters ensure peace-of-mind across the aerospace industry

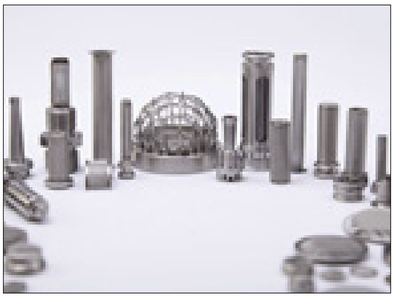
Porvair Filtration Group has announced that manufacture of its last chance aerospace filters is being extended to its US facility in Ashland, Virginia. Last chance filters help prevent sudden, catastrophic failure by providing final system protection and are required to meet stringent aerospace standards.

"After carefully investing in increased manufacturing capabilities at our Ashland facility last year, we have experienced major global interest in our last chance filters. It's clear that the aerospace industry is increasingly responding to stronger safety and environmental demands, with these filters at the top of the list for providing heightened protection, and generating peace-of-mind that translates to happier operators and travellers," stated Andy Cowan, Porvair's Aerospace Market Manager.

Porvair's last chance filters are predominantly made from sintered metal powder, with Porvair's media configurations including Sinterflo® F sintered metal fibre and Sinterflo® P sintered metal powder.

"The innovative design of our last chance filters also ensures a long service life, increased efficiency and reliability in the most demanding situations, whilst providing a cost-effective solution. We are keen to promote a new industry standard, and believe that this filter is an ideal starting point," added Cowan.

Last chance filters are among the most process critical elements that Porvair manufactures under strictly controlled conditions, providing critical point-of-use protection for contamination-sensitive components, and performing a complementary role to main system filters.



Last chance filters from Porvair

While main system filters are very effective, there can still be high levels of particulate contamination generated within the fluid system. Secondary last chance filters trap and retain contamination, such as machining chips, burrs, wear debris and fluid breakdown products, induced during operation or built in downstream of the main system filters.

The company's UK operation is currently manufacturing key components for the Airbus A350 and Bombardier's CSeries - among the world's most efficient aircraft.

www.porvairfiltration.com

Magna to acquire automotive transmission maker Getrag

Magna International Inc has announced that it has signed an agreement to acquire the Getrag Group of Companies, one of the world's largest suppliers of automotive transmissions. The purchase price for 100% of the equity of Getrag was stated as being around €1.75 billion.

Getrag has an 80-year history in transmissions and offers a range of transmission systems which include manual, automated-manual, dual-clutch, hybrid and other advanced systems. In addition to its wholly-owned operations, Getrag has significant joint-venture relationships with Ford, as well as Chinese auto makers Jiangling and Dongfeng. Other Getrag customers include BMW, Daimler, Renault, Volvo and Great Wall.

Including joint-venture locations, Getrag has approximately 13,500 employees and operates 13 manufacturing and ten engineering centres in nine countries. Getrag's 2014 consolidated sales were approximately €1.7 billion, which excludes approximately €1.6 billion in sales generated in its non-consolidated joint-ventures.

"As part of our ongoing product portfolio review, we have identified the expansion of our powertrain business as a strategic priority. Getrag is an excellent fit with this strategy," stated Don Walker, Magna's CEO.

"Getrag is a technology leader in a product area that we believe is well-positioned to benefit from industry trends that are driving increased vehicle fuel-efficiency and reduced emissions. Getrag's joint venture relationships also provide significant growth potential in China, the world's largest automotive market and the fastest growing market for DCTs. Lastly, Getrag has a highly capable and experienced workforce, including deep powertrain engineering expertise," added Walker.

www.magna.com

World PM2016 Call for Papers

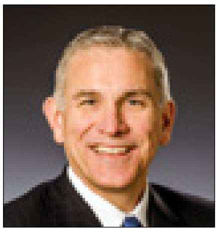
The World PM2016 Congress & Exhibition, organised and sponsored by the European Powder Metallurgy Association (EPMA), will take place in Hamburg, Germany, from October 9-13, 2016.

The Powder Metallurgy World Congress is held in Europe once every six years and is therefore an essential destination for those in the international PM community to meet suppliers, producers and end-users and to discover the latest innovations in the state-of-the-art PM technology.

A Call for Papers has now been issued and abstracts can be submitted online between September 1st and November 12th 2015. World PM2016 is an all topic event and includes both oral and poster sessions as well as a number of special interest seminars.

www.worldpm2016.com

Carpenter Technology names new President and CEO



Tony R Thene has been appointed Carpenter's President and CEO

Carpenter Technology Corporation has announced that its Board of Directors has appointed Tony R Thene as Carpenter's President, Chief Executive Officer (CEO) and member of the Board of Directors, effective July 1, 2015. Thene succeeds Gregory A Pratt, who will remain on the Board of Directors with additional responsibilities as interim Executive Chairman of the Board.

Thene currently serves as Senior Vice President and Chief Financial Officer of Carpenter Technology Corporation, where he has served since January 31, 2013. Thene joined Carpenter after 23 years with Alcoa Inc., where he most recently served as the Chief Financial Officer for Alcoa's Engineered Products and Solutions (EPS) business.

"On behalf of the Carpenter Technology Board of Directors, I am delighted to congratulate Tony as Carpenter's next President and CEO," stated Pratt. "After an exhaustive and far-reaching search process, the Board unanimously concluded that Tony is the candidate best suited to taking the Company to its next level of growth and profitability. He brings to Carpenter an outstanding record of accomplishment not only in his tenure here, but also during his time in both operating and financial roles at his previous companies. Tony has provided excellent leadership in our efforts to return Carpenter to previous profit levels. His involvement and commitment has resulted in recent improvements, and his continued oversight will ensure we meet the aggressive targets we have established. We are optimistic about Carpenter's future prospects under Tony's leadership and look forward to working closely with him."

In his role as interim Executive Chair, Pratt will be responsible for developing the overall corporate strategy and, in conjunction with the President and Chief Executive Officer, providing leadership and building consensus in the development of Carpenter's overall strategic plan, capital markets activities and corporate development initiatives within the context of the corporate strategy.

"Serving Carpenter for the second time as President and CEO over the past few months has been a great pleasure and a highlight of my career. I again would like to thank the Board, management team and our employees around the world for their hard work and support. Their efforts have been critical to our many accomplishments and in setting the stage for even greater future success. I look forward to assisting Tony and to ensure that we continue to build on our current momentum while effecting a smooth leadership transition."

www.cartech.com

ATI to expand nickel-based superalloy powder capabilities

Allegheny Technologies Incorporated (ATI) is investing around $70 million to expand its nickel-based superalloy powder production to satisfy strong demand from the aerospace jet engine market and growing demand from the Additive Manufacturing industry. The development is expected to take two years to complete and will be located at its Specialty Materials site near Monroe, USA.

"This strategic growth project will strengthen ATI's position in the production of technically demanding superalloy powders," stated Rich Harshman, ATI's Chairman, President and CEO.

"A significant portion of the powders to be produced from this expansion are needed to meet requirements of existing long-term agreements with jet engine OEMs that run well into the next decade. The expansion also better positions ATI to continue as a leading innovator supplying advanced powders to the new and rapidly growing Additive Manufacturing industry," added Harshman.

The expansion builds on ATI's existing powder capabilities located at facilities in Oakdale, Pennsylvania, which, ATI states, are currently operating near capacity.

www.atimetals.com

GTP acquires hardmetal recycling expert Tikomet

Global Tungsten & Powders (GTP), the tungsten powders division of Plansee Group, has announced the acquisition of Tikomet Oy. Tikomet is one of the leading producers of reclaimed hardmetal powders.

"The acquisition of Tikomet is a perfect strategic fit for us and increases the products that GTP can provide its customers," stated Dr Andreas Lackner, President and CEO of Global Tungsten & Powders Corp. While GTP uses a chemical recycling process of hardmetal, Tikomet has developed a recycling technology based on the zinc recycling process, which is economical and environmentally friendly.

Tikomet is located in Jyväskylä, 270 kilometres north of Helsinki, Finland, and has some 40 employees. The acquisition by GTP was signed on June 12th. The transaction is pending approval of the relevant authorities; financial details were not disclosed.

As an independent supplier to the hardmetal industry and with its state-of-the-art production facility and strong R&D capabilities, Tikomet has expanded the use of zinc reclaim powders into new applications resulting in strong market growth. "This transaction enables us to carry out the next step in our long term strategy: to be able to better serve our customers globally," added Dr Matti Kurkela, Managing Director of Tikomet.

The Tikomet facility in Finland

Global Tungsten & Powders, headquartered in Towanda, Pennsylvania, is one of the largest processors of tungsten raw materials in the western world with its history dating back to 1916. Pure tungsten, tungsten carbide and GTP's tungsten-based, ready-to-press tungsten powders are indispensable components of many products.

www.globaltungsten.com

POWDERMET2016 Call for Papers issued

The Metal Powder Industries Federation (MPIF) has issued a Call for Papers for its POWDERMET2016 International Conference on Powder Metallurgy and Particulate Materials, Boston, Massachusetts, USA, June 5–8, 2016.

Authors are requested to submit abstracts for papers to be presented in the general technical sessions and poster programmes no later than September 18, 2015. Abstracts can address all aspects of Powder Metallurgy and particulate materials technology.

The technical sessions will include the following categories:

- Design & Modelling of PM Materials, Components & Processes
- Particulate Production
- General Compaction & Forming Processes
- Powder Injection Moulding (Metals & Ceramics)
- Pre-Sintering & Sintering
- Secondary Operations
- Materials
- Refractory Metals, Carbides & Ceramics
- Advanced Particulate Materials & Processes
- Material Properties
- Test & Evaluation
- Applications

www.powdermet2016.org

New HIPed Venturi Flow Meter set to benefit oil and gas industry

Accura Group Limited, Wolverhampton, UK, and Advanced Interactive Materials Science Limited (AIMS), Peterborough, UK, have announced the development of a new Venturi Flow Meter, manufactured via the Powder Metallurgy process, used to accurately measure the flow of oil and gas as it comes out of the ground.

The Venturi Flow Meter is formed by AIMS, using HIPed Powder Metallurgy and near-net shaping techniques, and then precision machined by Accura to achieve internal engineering tolerances of two microns. Accura has an exclusive licence to market and sell the HIPed Venturi Valve globally.

"This new Venturi Flow Meter manufacturing technology is outstanding when it comes to performance, longevity, accuracy and integrity. With this product's mechanical properties and dimensional accuracy that more than meet the stringent oil and gas subsea standards, there is quite simply nothing like it in the marketplace," stated David Williams, Accura's Chief Executive.

"It is truly exciting and I believe the quality and performance standards achieved by AIMS and Accura will become the benchmark must-have Venturi Flow Meter globally. We have already received serious interest from various global oil and gas clients in North America, Asia and Europe," added Williams.

Replacing Venturi Flow Meters is a difficult and costly process, so components with high quality uniform material properties and highly engineered dimensional tolerances that reduce manufacturing risk and maintenance costs offer something the oil and gas industry is keen to exploit.

Alycidon Capital managing director Mark Hodgkins and Accura Chief Executive David Williams

"We are delighted to be teaming up with another Midlands business established in the global oil and gas market that shares our passion for delivering the highest quality products that minimise manufacturing risk and maintenance costs. The AIMS team has been working hard to perfect various HIPed and near-net shaped components, which are at the cutting edge of manufacturing technology," stated Mark Hodgkins, Managing Director of AIMS.

www.aimsltd.com
www.accura.co.uk


POWDERMET
2016
POWDERMET2016
JUNE 5–8 • MPIF/APMI
BOSTON
2016 INTERNATIONAL CONFERENCE ON POWDER METALLURGY & PARTICULATE MATERIALS
June 5–8, 2016
Sheraton Boston • Boston, MA
TECHNICAL PROGRAM
Over 200 worldwide industry experts will present the latest in powder metallurgy and particulate materials.
TRADE EXHIBITION
Over 100 companies showcasing leading suppliers of powder metallurgy and particulate materials processing equipment, powders, and products.
SPECIAL CONFERENCE EVENTS
Including special guest speakers, awards luncheons, and evening networking events.
Visit POWDERMET2016.org to submit an abstract, to reserve an exhibit booth or for program details.
METAL POWDER INDUSTRIES FEDERATION
APMI INTERNATIONAL
Held in conjunction with:
AMPM
Additive Manufacturing
With Powder Metallurgy
June 5-7, 2016 BOSTON
PAUL REVERE

Metaldyne earns Ford World Excellence Award

Metaldyne LLC, headquartered in Plymouth, Michigan, USA, has announced that its Bluffton, Indiana, operation has received a Ford Motor Company World Excellence Award. The awards are given to suppliers who exceed company expectations and distinguish themselves from their peers by achieving the highest levels of global excellence in terms of quality, delivery and total cost.

Metaldyne stated that over the last year its Bluffton, Indiana facility delivered exceptional results for Ford. The operation has significantly increased capacity for six speed transmission clutch modules without any material quality issues, while maintaining on-time deliveries.

"This recognition from our largest customer is a testament to the outstanding work from all our employees at our Bluffton operation," stated Thomas A Amato, President and CEO, Metaldyne, and Co-President, Metaldyne Performance Group. "Our transmission products are manufactured with a highly sophisticated process with tight tolerances, and the Bluffton team's combination of leading technology and a strong commitment to quality have helped us earn this prestigious award."

Metaldyne manufactures, machines and assembles a variety of transmission products, including clutch modules, differential gears and assemblies, end cover assemblies and aluminium valve bodies.

www.metaldyne.com

Mitterbauer Beteiligungs AG plans takeover offer to free-float shareholders and delisting of Miba AG

Miba AG has been informed by its majority shareholder, Mitterbauer Beteiligungs-Aktiengesellschaft (MBAG), that a takeover offer addressed to free-float shareholders is planned. The company was also informed that MBAG targets a squeeze-out and a delisting of the Miba preferred shares from the Vienna Stock Exchange, likely in the fourth quarter 2015.

MBAG intends to make a voluntary public offer in accordance with Sections 4 et seq of the Austrian Takeover Code ("ATC") to the shareholders of Miba to purchase all no par value preferred bearer shares Issue B of Miba which are listed for trading on the Vienna Stock Exchange.

The offer price will amount to €550 per preferred share and the offer document is expected to be published on or about July 30, 2015. The offer period will commence upon publication of the offer and will presumably last three weeks.

www.miba.com

Colin DeVille joins Poudres Hermillon

U.S. Metal Powders, Inc. (USMP), the parent company of Poudres Hermillon SARL, has announced that Colin DeVille has joined Poudres Hermillon as General Manager, effective September 1, 2015.

USMP has two aluminium powder production facilities, Ampal in Palmerton, Pennsylvania, USA, and Poudres Hermillon in France.

"We are extremely proud and privileged to have Colin head up Poudres Hermillon SARL," stated Clive Ramsey, President & CEO of USMP.

"At the helm of Poudres, Colin will be guiding the French company in both its conventional nodular and spherical aluminium and aluminium alloy powders and its ultra-fine powders specifically designed for advanced production processes including Metal Injection Moulding, 3D Printing and Additive Manufacturing," added Ramsey.

www.poudres-hermillon.com

Powder Metallurgy Day at Ceramitec to focus on metal and ceramic Additive Manufacturing

Ceramitec 2015, the international trade show for the entire ceramics industry, ranging from conventional ceramics and raw materials to Powder Metallurgy and technical ceramics, will take place at Messe München, in Munich, Germany, from 20 to 23 October 2015.

The Supporting Programme will provide a platform for the transfer of knowledge and expertise in research and development. Attendance at the specialist lectures and panel discussions will be free of charge and simultaneous translation in German and English will be offered for all lectures.

This year's programme will begin with a panel discussion themed "Ceramitec goes digital" on the opening day, Tuesday 20 October 2015. Experts from ceramics and Powder Metallurgy will report on progress in Additive Manufacturing, with regard to industrial realisation and further needs for research and development.

The theme continues during the afternoon of the first day with the Powder Metallurgy Day programme, organised by the Fachverband Pulvermetallurgie, including presentations on dynamic developments in metal and ceramic Additive Manufacturing.

www.ceramitec.de

We will be exhibiting at Ceramitec 2015. Please visit us on stand B1/511 and pick up your free copies of *Powder Metallurgy Review, Metal AM* and *PIM International* magazines.

Sept. 22–25, 2015
Düsseldorf
Exhibition Center
euromold.
World Fair for Mold- and Patternmaking, Tooling, Design, Additive Manufacturing and Product Development.
From Idea to Series Production.
Innovations for any purpose.
New trends and products at Euromold – in Düsseldorf.
Euromold is the world's leading marketplace for new products. From engineering and mouldmaking to 3D printing, all international key players and manufacturers gather here to present the best of innovations.
Visit Euromold in Düsseldorf and get inspired by the unique diversity of new products!
Visit us: www.euromold.com
© Image source: Vogel Business Media

Seco/Warwick to hold its Heat Treat Summit in Pennsylvania, USA

Seco/Warwick has announced that its Heat Treat Summit will take place September 14-16, 2015, in Erie, Pennsylvania. The event will present the latest engineering solutions and technological developments for thermal processing.

This year's Summit will include 16 guest speakers. Dr Richard Sisson will open the event with the latest developments in Nanomaterials from the Centre for Heat Treating Excellence (CHTE), Worcester Polytechnic Institute, followed by Dan Herring presenting the Heat Treat Market Outlook for 2015. Steve Kowalski, 2015/2016 ASM Heat Treat Society President will provide insights into the future of the Society.

www.secowarwick.com

Changes announced to Rio Tinto's management team

Rio Tinto has announced that Vania Grandi has succeeded Greg Lavallee in the position of General Manager Metallics within the Rio Tinto Iron & Titanium Commercial group. Vania started with the metallics team in August 2014 on the development of RTIT commercial strategy and moved into the General Manager role on April 1st. Previously, Vania had been working in the Copper Product Group where she had senior leadership responsibilities for Marketing, Sales and Sustainable Development.

Greg Lavallee remains with the Rio Tinto Iron & Titanium Commercial team as Project Executive.

In his new role, Lavallee is responsible for the expansion of the powder business. He is also working on the development and implementation of critical business transformation projects for Rio Tinto Iron & Titanium.

Vania Grandi (left) and Vladimir Paserin (right) have begun new positions within Rio Tinto's management team

The company also announced that Vladimir Paserin has been appointed Scientific Manager for Rio Tinto Metal Powders and will be responsible for leading the R&D activities that are related to new powder products. Paserin has over 20 years of experience in product development including Nickel powder industries.

www.qmp-powders.com

An introduction to Powder Metallurgy Soft Magnetic components: Materials and applications

Powder Metallurgy soft magnetic components can be found in a wide range of applications, with the automotive sector being the largest consumer. A variety of soft magnetic materials are available in powder form and the PM process offers the advantage of net-shape production for many high performance high cost materials. In this article Dr Mark J. Dougan, Chief Metallurgist in the R&D department at PM parts maker and soft magnetic specialist AMES SA, Spain, describes the production process, materials and applications for sintered soft magnetic materials.

Powder Metallurgy is well established as a process for the production of soft magnetic components for electromagnetic applications. There is a wide range of applications for soft magnetic materials, from the automotive sector to electronics and information technology. The list is continually growing with advances in materials and the development of new applications.

The term soft in relation to magnetism refers to materials which are easily magnetised under the influence of an external magnetising field and which give up their magnetisation when the external field is removed. These materials are principally the ferromagnetic elements iron, nickel and cobalt and their alloys. Unlike hard magnetic materials, or permanent magnets, which retain their magnetisation in the absence of an external field and are used as sources of magnetic flux, soft magnetic materials are used as guides and amplifiers of magnetic flux. They act as a conduit in magnetic circuits allowing electrical signal to be converted to movement, as in the case of motors or actuators (Fig. 1), or movement to be converted to electrical signal, as in the case of sensors. The complicated geometries required to form magnetic circuits are well suited for PM production by pressing and sintering. Table 1 identifies the range of products currently in production at AMES.

Fig. 1 These actuator components allow an electrical signal to be converted to movement

Sensors	
Sensors for ABS brakes, camshafts, crankshafts, etc, made of plain Fe, Fe-P, or ferritic stainless steel	
Actuators	
Coil cores, armatures, poles, stators, etc, for a multitude of different linear and rotary actuators, in materials ranging from plain Fe or Fe-P, to Fe-Si, Fe-Ni or Fe-Co, depending on the required magnetic characteristics. Applications include solenoid valves, injectors, regulation systems, EGR, SCR, etc	
Soft Magnetic Composites (SMC's)	
Components made from Soft Magnetic Composites, able to work at high frequency (> 400 Hz). Typical applications are rotors and stators for electric motors, inductive components, injectors, ignition coils, and special actuators	
Others	
Coil cores for high sensitivity Detectors-Sensors-Contactors, made of Fe-Ni	
Small components made of Fe-Co, used to maximize the induction/volume ratio in order to reduce the occupied space	
Customised magnetic components for many different applications: contactors, pole shoes, electric motors, magnetic brakes, etc	

Table 1 A wide range of sintered soft magnetic components is manufactured at AMES

Properties of soft magnetic materials

Hysteresis loop

Analogous to the way in which the important mechanical properties of a structural steel can be characterised from a stress-strain plot, the important magnetic properties of a soft magnetic material can be obtained from a plot of induction (B) versus applied field (H), known as a hysteresis loop, as shown in Fig. 2.

An initially unmagnetised sample is subjected to an increasing field and the flux density or induction resulting in the sample is recorded up to a maximum value, B_{max}. If the applied field is sufficiently large, the sample may become fully magnetised, or saturated, in which case $B_{max} = B_{sat}$, the saturation induction. The induction is a measure of the force which a magnetic field can exert. This section of the hysteresis loop is known as the initial magnetisation curve.

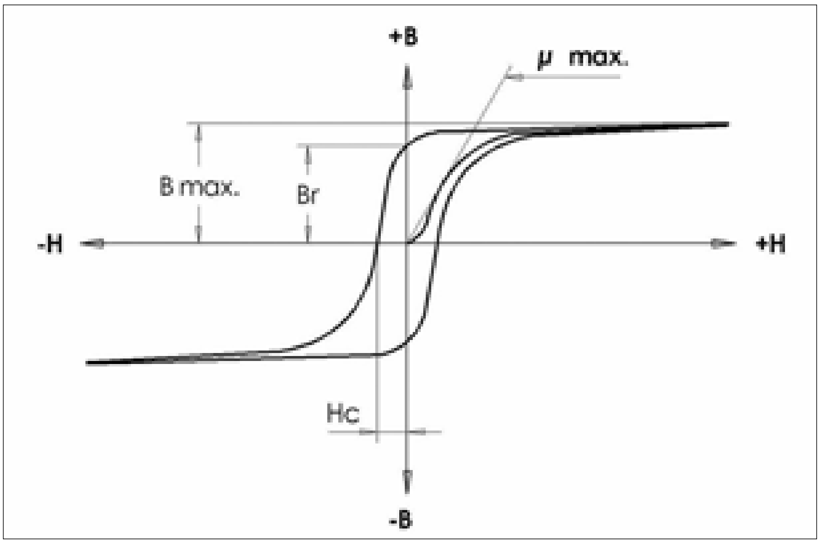


Fig. 2 Hysteresis loop for a ferromagnetic material

Permeability

The coefficient of proportionality between applied field and induction is known as the permeability. The higher the permeability, the greater will be the induction produced by a given applied field. In ferromagnetic materials, the permeability is not a constant and so materials are generally ranked by their maximum value μ_{max}.

If the applied field is then reduced to zero, the induction will not reduce along the same path; the magnetisation curve shows hysteresis. In an unmagnetised sample of ferromagnetic material which has not been subjected to an external field, the magnetic moments of the atoms are subdivided into magnetic domains of opposing orientation, which cancel each other out, leaving no overall net magnetisation. As the unmagnetised sample is subjected to an increasing applied field, these magnetic domains rearrange themselves, with domains which are approximately aligned with the external field growing at the expense of domains which are aligned against the applied field. This happens by the movement of the domain walls separating the differently aligned regions.

Imperfections in the crystalline structure of the material, such as vacancies, dislocations, inclusions, second-phase precipitates or grain boundaries, represent an obstacle to the free movement of these domain walls, which requires additional energy to be overcome. It is this which leads to hysteresis when the external field is removed.

Coercive force

When the external field is reduced to zero, a certain net magnetisation will remain, known as the remanent induction or B_r. Additional energy must be expended, in the form of an external field in the opposite direction to the original magnetising field, in order to reduce the magnetisation of the sample to zero. The magnitude of this field is given the nomenclature H_c, and is referred to as the coercive force or coercivity of the material. The higher the permeability of a material, the easier it is to magnetise. The lower the coercive force, the easier it is to demagnetise. The hysteresis loop is completed by increasing the applied negative field to once again reach saturation, and then reversing the cycle. The area under the loop gives the energy expended per cycle to change the magnetisation of the material. Multiplied by the frequency of magnetisation, this gives the hysteresis losses, measured in Wkg^{-1}.

Production of sintered soft magnetic parts

The production of sintered soft magnetic parts is broadly similar to the production of structural steel parts. High densities favour high induction. Except in the low field region of the B-H curve, induction varies linearly with density. Other factors being equal (type of iron powder, sintering conditions, process route), an increase in density of 0.1 g/cm³ gives an increase in induction of 0.05 T (Fig. 3).

High permeability and low coercive force are favoured by high purity powders, a large grain size and very low oxygen, nitrogen and carbon levels. In the sintering of structural parts, fast cooling rates are advantageous to refine microstructure and increase strength. In the sintering of soft magnetic components on the other hand, slow cooling rates are favoured in order to promote grain growth.

Optimum results are obtained by sintering at high temperature (>1250°C) in a pure dry hydrogen atmosphere in order to avoid nitrogen pick-up, encourage grain growth and produce smaller, more rounded pores to minimise the generation of internal demagnetising fields. Particular care must be exercised in the dewaxing phase in order to avoid carbon contamination.

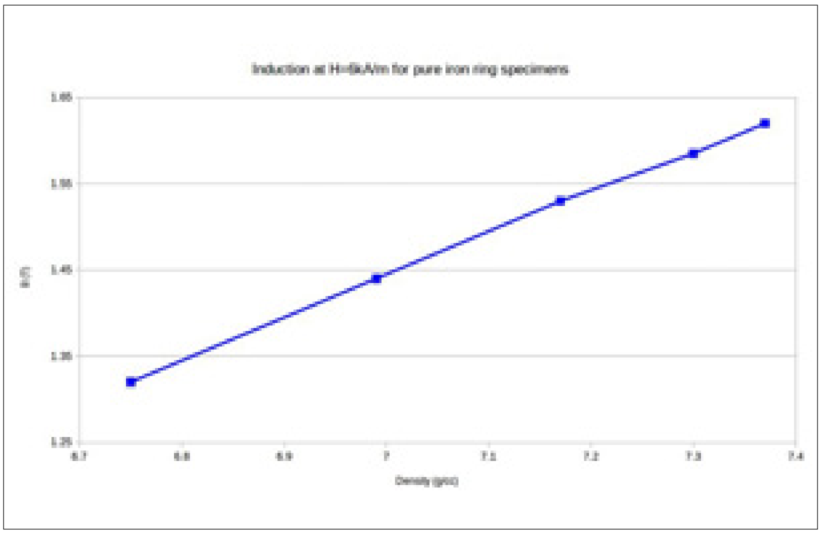


Fig. 3 The variation of induction with density for pure iron samples sintered at 1120°C

Finishing operations

If soft magnetic parts are submitted to finishing operations which leave residual stresses, such as sizing, machining or tumbling, then a stress-relieving anneal will be required to restore the permeability and coercive force to their as-sintered values. The coercive force is also an important parameter for the quality control of soft magnetic parts, since, unlike the permeability, it can be measured directly from a finished component.

Pure Iron components

In the world of PM parts production, where we are constantly looking for more sophisticated alloying systems to obtain higher strengths in structural components, plain iron might seem to be too simple a material to be of much interest. In fact, due to its very high level of induction, it is an extremely important material for soft magnetic applications. The excellent compressibility of pure iron makes it easy to reach high densities, its dimensional stability on sintering makes tight tolerances achievable and it has the lowest cost of the PM soft magnetic materials.

Table 2 shows the properties typically obtainable from pure iron at different densities. The values shown at a density of 7.2 g/cm³ were obtained after sintering at 1120°C, while those shown at 7.6 g/cm³ were obtained after sintering at 1250°C.

For many years the most typical examples of sintered pure iron parts were the toothed reluctor rings (also known as tone rings) used in automotive anti-lock braking systems. These ABS rings were produced in many sizes and designs (Fig. 4), but all operated on the same principle (Fig. 5). Attached to axles or driveshafts, they allow the rotation of the wheels to be monitored, with the movement of the teeth past an inductive sensor causing fluctuations in a magnetic field, which generates an alternating voltage from the sensor coil. The frequency of the output signal is related to the wheel speed and the number of teeth on the sensor ring. If the alternating signal ceases, it indicates that the wheel is no longer rotating.

Material	Density (g/cm³)	Coercive Force (Am^{-1})	Saturation Induction B_S (T)	μ_{MAX}	UTS (MPa)	Elongation (%)	Rockwell Hardness
Pure Iron	7.2	150	1.8	3000	220	10	56F
	7.6	80	2.05	6000	250	30	50F

Table 2 Magnetic and mechanical properties of sintered pure iron

Fig. 4 Toothed sensor rings produced from sintered iron for antilock braking systems

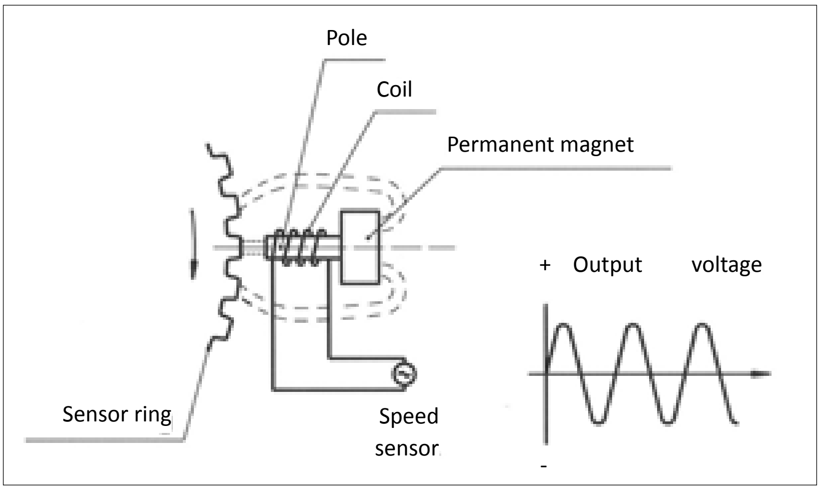


Fig. 5 Operating principle of an ABS sensor ring

Fig. 6 A variety of target wheels produced from sintered iron used in camshaft position sensors

Although this is a robust system mounted in millions of vehicles, it has the disadvantage that not only the frequency but also the amplitude of the output signal decreases with the rotational speed of the sensor ring and, below vehicle speeds of a few km/h, it is too low to be read. For this reason, in recent years anti-lock braking systems have moved away from using passive sensors and toothed rings to active sensor arrangements, which are more reliable at low speeds. However, the same principles are used in other kinds of toothed and slotted sensor disks. The use of an asymmetric profile allows not only speed of rotation but also position to be measured using inductive or Hall-effect sensors. This kind of part is used in camshaft position sensors such as those shown in Fig. 6.

The use of pure iron sintered parts is not restricted to automotive applications. Fig. 7 shows pure iron components forming part of an electromagnetic disk brake used in home automation systems for the opening and closing of blinds and sun awnings.

Increasing strength with phosphorus

Pure iron, for all its magnetic virtues, is a material with insufficient strength and hardness for many applications. Carbon cannot be added to increase the strength of iron without adversely affecting its soft magnetic properties, increasing its coercivity to the point where it effectively becomes a permanent magnet. In fact, the use of the terms soft and hard to classify the magnetic behaviour of a material originally derive from the observation that hard carbon steel retained magnetisation to a much greater extent than soft malleable iron.

Fortunately, phosphorus, which is the next most potent ferrite strengthening element after carbon, can be added to iron to increase strength and hardness without any loss of magnetic properties. In fact, phosphorus iron will generally show lower coercive force and higher permeability than pure iron at the same density. This is because the phosphorus is a ferrite-stabiliser, and allows partial alpha-phase sintering, leading to much larger ferrite grain size, an effect which is particularly noticeable in phosphorus iron sintered at high temperature as shown in Fig. 8. A large grain size favours the free movement of magnetic domain walls.

Table 3 lists sample properties for the most commonly used composition; iron alloyed with 0.45% phosphorus. This composition is a popular choice due to its dimensional stability when sintered at 1120°C. The values at a density of 7.2 g/cm^3 were obtained from samples sintered at 1120°C, while the samples at a density of 7.6 g/cm^3 were sintered at 1250°C. The increase in permeability due to increased grain size after high temperature sintering is clear.

The combination of magnetic and mechanical properties of Fe-P has led it to be widely used in the production of components for linear actuators such as flux washers, pole plates and housings, which are often crimp-fitted. These linear actuators are used in fuel injectors or in solenoids, which increasingly are replacing vacuum or mechanically activated devices.

Fig. 8 shows a flux tube and pole piece, which form part of a solenoid for a module used to provide electro-hydraulic control of automatic and dual-clutch transmissions. Several such solenoids are used in each module.

Increased resistivity with addition of silicon

Iron alloyed with 3wt% of silicon has a higher hardness than phosphorus iron and can be used for applications requiring increased resistance to wear or impact such as the plungers

Fig. 7 Pure iron parts used in an electromagnetic disk brake in a home automation system

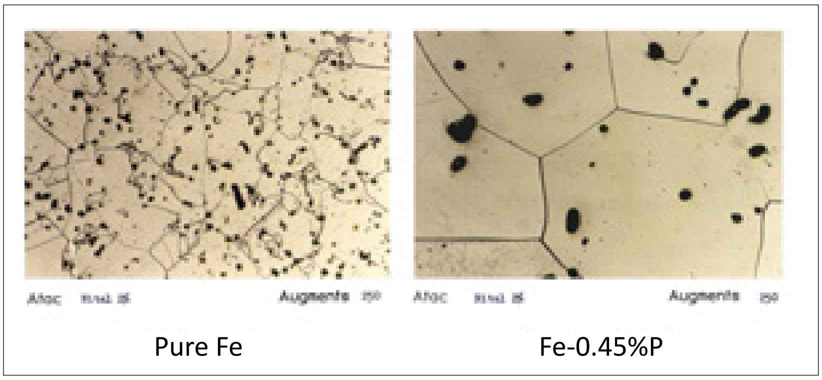


Fig. 8 The ferrite grain size in pure iron and phosphorus iron after high temperature sintering

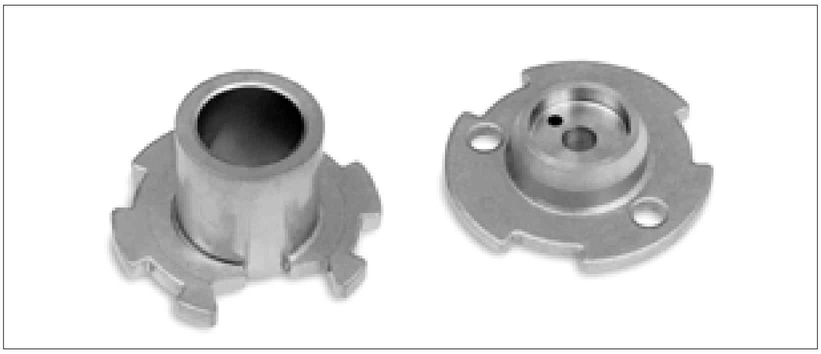


Fig. 9 Flux tube and pole piece from a solenoid, produced from sintered Fe-P

Material	Density (g/cm^3)	Coercive Force (Am^{-1})	Saturation Induction B_s (T)	μ_{MAX}	UTS (MPa)	Elongation (%)	Rockwell Hardness
Fe – 0.45% P	7.2	106	1.8	4400	350	14	63B
	7.6	44	2	10900	500	20	68B

Table 3 Magnetic and mechanical properties of sintered phosphorus iron

Material	Density (g/cm³)	Coercive Force (Am⁻¹)	Saturation Induction B_S (T)	μ_{MAX}	Resistivity (μΩcm)	UTS (MPa)	Elongation (%)	Rockwell Hardness
Fe – 3% Si	7.3	64	1.8	8000	50	400	15	70B
	7.5	48	1.9	9500	48	410	17	79B

Table 4 Magnetic and mechanical properties of sintered silicon iron

Material	Density (g/cm³)	Coercive Force (Am⁻¹)	Saturation Induction B_S (T)	μ_{MAX}	UTS (MPa)	Elongation (%)	Rockwell Hardness
Fe – 50% Ni	7.9-8.05	5-16	1.6	25000-30000	420	18	64B
Fe – 80% Ni	8.5	2	0.8	74900	440	20	68B

Table 5 Magnetic and mechanical properties of sintered nickel irons

or armatures in linear actuators. However, the main benefit of the alloying of iron with silicon is the resultant increase in resistivity, by a factor of four relative to pure iron, which allows magnetic properties to be maintained in applications where the frequency of magnetisation-demagnetisation is higher than a few hertz.

Sintered silicon iron parts are prepared from a pure iron base powder mixed with a ferro-silicon master alloy. As well as reducing the compressibility relative to pure iron or iron-phosphorus, this makes high temperature sintering (above 1250°C) an absolute requirement, both in order to achieve homogenisation of the composition and to promote the large grain size required for optimum permeability and coercive force. Best results are obtained by sintering in a pure hydrogen atmosphere. Table 4 lists the properties achievable in Fe-3%Si at two density levels.

Fig. 10 Parts for linear actuators produced from sintered silicon iron

Fig. 10 shows a variety of parts produced from sintered silicon iron. The parts labelled 1 and 2 are, respectively, an armature and stator ring used in electronically-controlled unit injectors for heavy-duty diesel engines of the sort used in lorries, buses or marine applications. Both of these parts are produced at a density of 7.4 g/cm³.

At an even higher density of 7.5g/cm³, 3% silicon iron is currently finding application as the material for the pole pieces in the metering pumps for AdBlue, which are being used in selective catalytic reduction (SCR) systems being introduced in passenger vehicles to allow them to comply with Euro VI NOx emission levels.

Nickel-irons offer high permeability and low coercive force

The nickel-irons, often referred to as Permalloys, are the family of soft magnetic materials with the highest permeabilities and lowest coercive forces. An alloy with 80%Ni can give a permeability of around 75000, with a coercive force as low as 2 Am⁻¹, though this comes at the expense of a very low saturation induction in comparison with pure Fe. Fe-50%Ni combines a relatively high maximum induction with very high permeability and low coercive force and is the most widely-used of the sintered nickel irons. Table 5 lists the properties obtainable for 50% and 80% nickel-irons: in both cases, these values are obtained on sintering at temperatures above 1250°C in a dry hydrogen atmosphere.

Fig. 11 shows a comparison of the B-H curves of Fe-50%Ni and Fe-0.45%P at low values of applied field. The nickel iron sample had a density of 7.9 g/cm³, while the Fe-0.45%P had a density of 7.6 g/cm³ (similar proportions of their respective full densities). While the phosphorus iron has a much higher saturation induction, at applied fields of up to 100 Am⁻¹, it is the nickel iron which has the higher induction. To achieve an induction of 0.46 T in the nickel iron requires only one quarter of the applied field required in the phosphorus iron. This makes nickel-iron an excellent choice for low current drain applications, such as battery-powered valves and switching systems.

Fig. 12 shows a selection of parts produced from sintered nickel iron. The parts labelled 1 and 2 are the closure plate and core from a high-speed pneumatic valve.

Banks of such valves are used in automated sorters for foodstuffs such as peas or rice. The product to be sorted falls in a continuous stream past artificial vision cameras and, when contaminants or out-of-specification items are detected, the valves are triggered to cause a jet of compressed air to remove the unwanted item from the product stream.

Because of the very high throughput of such machines, the opening and closing times of the valve are of paramount importance. A few milliseconds' delay in opening the valve and the contaminant would not be rejected, while any lag in closing the valve would lead to rejection of good product. To achieve such rapid opening and closing, very high permeability and very low coercive force are needed and the core and closure plate are therefore produced from Fe-50%Ni, with a density above 7.95 g/cm³, sintered at high temperature in a dry hydrogen atmosphere. No other material could give the required performance.

Nickel iron is a high value material: Fe-50%Ni can cost between ten and fifteen times as much as pure iron. This makes the net-shape PM process a particularly attractive production route, even for fairly simple shapes, through the avoidance or minimisation of material waste.

It should be mentioned that the permeability and coercive force of the nickel irons are extremely sensitive to cold work and even fairly small amounts of deformation can cause the coercive force to increase by one or even two orders of magnitude. Particular care must be taken in part handling and assembly and, if finish machining operations are required, they must be followed by high-temperature annealing.

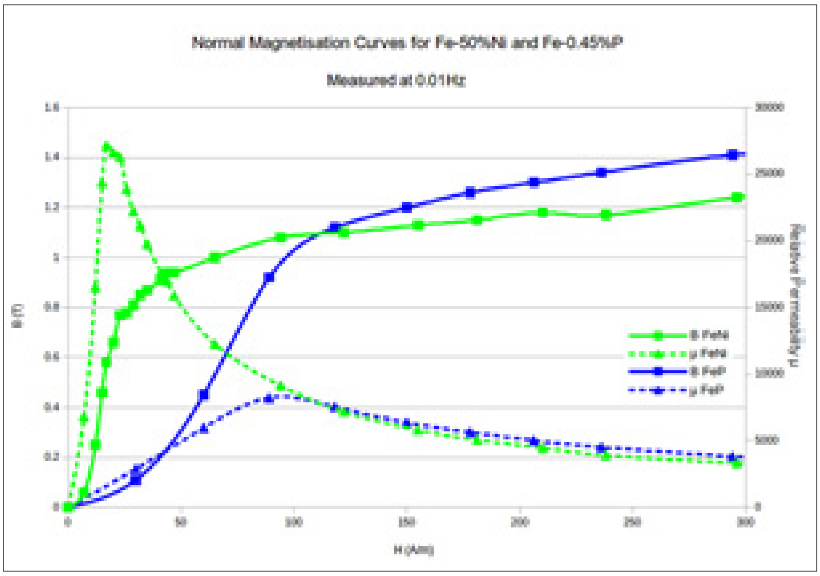


Fig. 11 DC B-H Curves for sintered Fe-50%Ni and sintered Fe-0.45%P

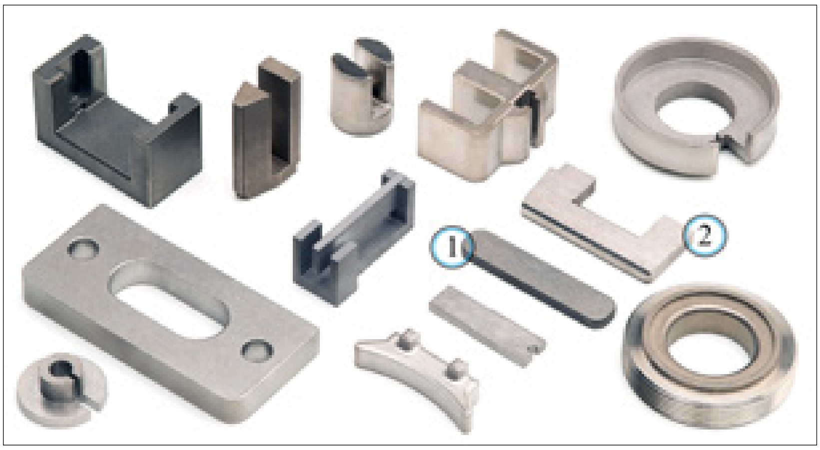


Fig. 12 A selection of parts produced from sintered nickel iron

High values of saturation magnetisation with cobalt-iron

The value of cobalt-iron alloys lies not in their permeability, but rather in extraordinarily high values of saturation magnetisation, the highest of the soft magnetic materials. An alloy of iron with 35% Cobalt can give a saturation induction of more than 2.4 T, but an alloy of Fe-50%Co, known as Permendur, is generally preferred due to its offering improved permeability with only a slightly lower value of saturation magnetisation.

Table 6 shows properties typically obtained in sintered Fe-50%Co. The ranges of values depend on a final annealing treatment, which can be varied to favour magnetic or mechanical properties.

Fig. 13 shows B-H curves for samples of Fe-50%Co and pure iron. The pure iron sample was pressed, high-temperature sintered and sized to a density of 7.71 g/cm³, followed by full annealing. The cobalt iron sample was pressed and sintered to a density of 7.98 g/cm³. At an

Material	Density (g/cm³)	Coercive Force (Am^{-1})	Saturation Induction B_s (T)	μ_{MAX}	UTS (MPa)	Elongation (%)	Rockwell Hardness
Fe-50% Co	>7.95	150-180	2.35	3000-4000	200-400	<1 - 2	85B

Table 6 Magnetic and mechanical properties of sintered cobalt iron

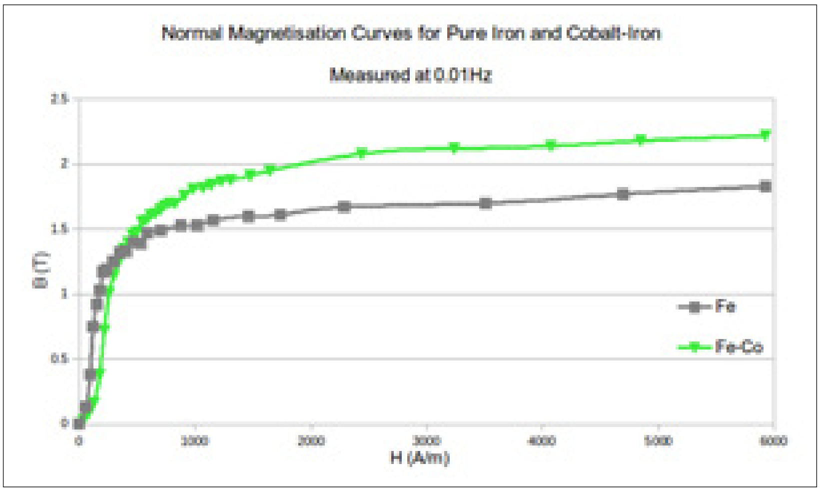


Fig. 13 DC B-H curves for sintered pure iron and sintered cobalt iron

applied field of 5.9 kAm-1, the cobalt iron shows an induction of 2.22 T, nearly 0.4 T higher than the pure iron. Magnetic force varies with the square of flux density and, hence, this difference in induction could give almost a 50% increase in force. It is for this reason that cobalt iron is the material of choice for applications such as pole pieces for electromagnets, beam guide systems for electron microscopes and high-efficiency motors and generators, which require either the maximum possible force or the minimum possible size of component to produce a given force.

A further advantage of cobalt-iron is its high Curie point, the temperature at which thermal agitation overcomes ferromagnetism. A Fe-50%Co alloy has a Curie temperature of around 950°C, compared with 770°C for pure iron. This allows cobalt iron to maintain its magnetic properties will little degradation up to temperatures around 500°C, making it the only choice of material for applications with high working temperatures such as the cores of ultra-compact motors where space constraints do not allow for adequate cooling.

PM might be considered to be an under-exploited production route for cobalt iron. Even more so than nickel iron, cobalt iron is a high value material, costing up to 50 times the price of pure iron. It is also notoriously difficult to machine, earning it the nickname "crackalloy" among machinists. This increases the value of a net-shape forming process, avoiding wasted material and avoiding or minimising slow and difficult machining operations.

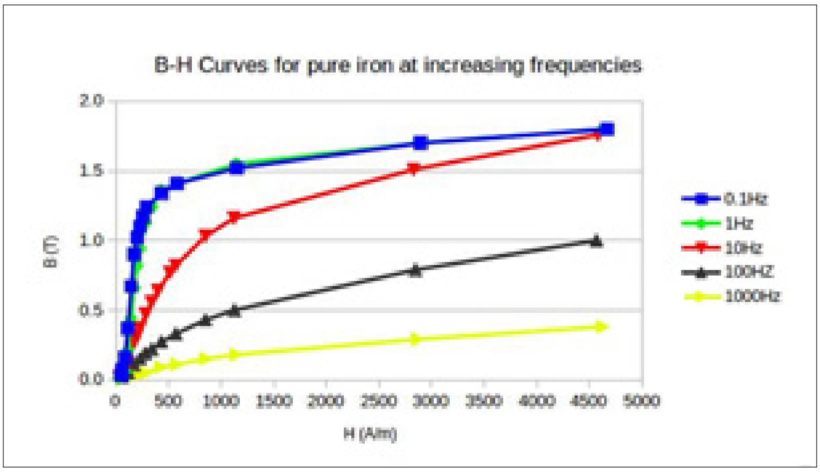


Fig. 14 B-H curves for sintered pure iron at different magnetising frequencies

Soft magnetic materials for high frequency applications

The materials described thus far are suitable primarily for applications under conditions of static magnetisation, or when the magnetisation-demagnetisation cycle occurs at a frequency of no more than a few hertz. When the frequency of the magnetisation/demagnetisation cycle is increased beyond this, the properties of conventional sintered soft magnetic materials show a rapid deterioration.

Fig. 14 shows a sequence of B-H curves measured from a sample of sintered iron at frequencies from 0.1 to 1000 Hz. Above 1 Hz, the permeability and maximum induction show a significant fall-off. This fall off is due to the generation of eddy or Foucault currents in the iron sample.

According to Faraday's law, a variation in the intensity of a magnetic field generates a voltage or electromotive force, which is proportional to the rate of change of the flux density. In an electrically conductive medium, such as a soft magnetic iron, this will cause loops of current to flow. The more rapid the change in the magnetic field, the greater is the amount of energy which will be dissipated in the form of resistive heating of the iron part. The eddy currents will themselves induce a secondary magnetic field, which opposes the change. The overall effect is observed as a severe decline in the permeability of the material as the frequency of magnetisation increases.

The losses due to eddy current formation are given by equation (1),

$$P_e = \frac{K\ d^2\ f^2\ B^2}{\rho} \qquad (1)$$

where K is a constant, f is the frequency of the magnetising cycle, B is the maximum induction attained, d is the smallest dimension of the material perpendicular to the magnetic field and ρ is the electrical resistivity of the material.

The increased electrical resistivity of iron alloyed with silicon mitigates the problem of eddy current forma-

Property	Typical values
μ_{MAX}	300-1000
B_{max} at $10kAm^{-1}$ (T)	1.32-1.63
TRS (MPa)	30-140
Losses at 1T, 400Hz (W/kg)	32-63
Resistivity (μΩ.m)	70-22200

Table 7 Ranges of properties obtainable in different SMC materials

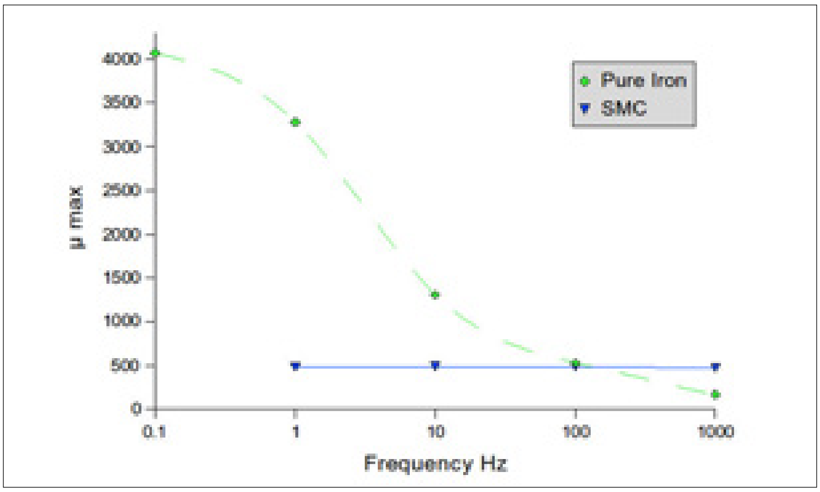


Fig. 15 Variation of maximum permeability with frequency of magnetisation for sintered pure iron and an SMC material

tion to a certain extent and Fe-3%Si can be used at frequencies up to a few tens of hertz. The resistivity could be increased still further by increasing the amount of silicon beyond 3wt%, but, in practice, the resultant loss of compressibility and increase in fragility makes this impractical and, since the eddy current losses increase with the square of the frequency of magnetisation, an increase in the resistivity alone is not sufficient.

The traditional method of restricting eddy current losses is to reduce the value of *d* in equation (1) by using a laminated stack of thin sheets of silicon steel separated by an electrically insulating varnish. In this way, *d* may be reduced from tens of millimetres to 0.5 mm or less. Since the eddy current losses are proportional to the square of this parameter, such a reduction in *d* has a significant limiting effect.

Soft Magnetic Composite (SMC)

In the world of PM materials, the alternative to the laminated stack is the Soft Magnetic Composite or SMC. Here, it is the iron powder grains, which are separated from each other by an electrically insulating layer, either in the form of a phenolic or silicone resin or in the form of an oxide or phosphate coating of the powder. In this way, the parameter *d* is reduced still further, down to the size of the powder grain, typically from 20 to 120 μm. In comparison with laminated stacks, SMC materials offer a greater resistance to eddy current formation, as well as presenting designers with the advantage of magnetic properties which are isotropic, rather than being confined to two dimensions as in the case of laminates.

SMCs are a special class of PM material, as they are not sintered. Sintering at conventional temperatures would break down the insulating barrier between iron particles and, hence, these materials are subjected to a curing treatment at a much lower temperature, typically up to 500°C. As a consequence, these materials have much lower mechanical strength than conventional sintered materials, with a TRS of 140 MPa representing the upper limit of what is currently achievable. A further consequence of the low curing temperature is that there is no effective stress relief for the cold work done during the compacting process.

This means that the coercive forces of these materials are relatively high and their permeabilities are relatively low in comparison with conventional sintered irons. In practice, however, this is not a problem at the working frequencies for which these materials are designed. Fig. 14 shows the maximum permeability of a sintered pure iron and a soft magnetic composite material (Somaloy 500 made by Höganäs AB) at different magnetising frequencies. Although the permeability of the SMC material is much lower than that of the sintered iron at low frequencies, it remains constant as the frequency is increased, while that of the sintered iron drops off sharply. At frequencies above 100 Hz, the permeability of the SMC material is higher.

SMC grades

In recent years, the number of grades of SMC materials available has proliferated, with variations to the base powder grain size and the type and quantity of insulator allowing the properties of the material to be targeted to specific types of application. SMC grades are now available, which permit curing at temperatures high enough to give effective stress relief, allowing maximum permeabilities of up to 1000 to be achieved. Raising the permeability much beyond this level is limited by the insulating layers within the material forming a distributed air gap. Improved pressing lubricants and the use of warm compaction allow high densities (>7.5 g/cm^3) to be achieved in order to maximise induction. Other grades have insulating systems, which allow them to operate at frequencies of tens or hundreds of kHz. Table 7 shows the ranges of properties available from currently available SMC materials.

SMCs are increasingly being chosen for the production of high efficiency motors, ignition cores,

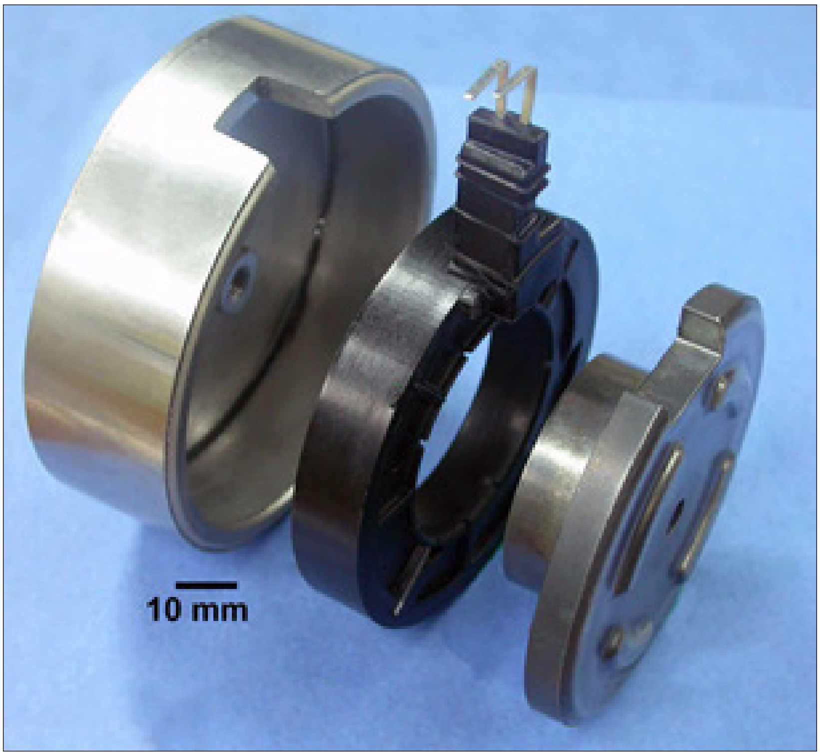


Fig. 16 Orifice plate, winding, and core plate from a variable stiffness engine mount

transformers, chokes, sensors or fuel injector cores. Fig. 16 shows components from two types of PM soft magnetic material, which form part of a variable stiffness engine mount. The part on the left is an orifice plate fabricated from Fe-0.45%P while the part on the right is a core plate produced from an SMC material. By varying the magnetic field in the core plate, the viscosity of a magnetorheological fluid is altered and, hence, its resistance to passing through the slots in the orifice plate. This system is used in the Porsche 911 GT3 to improve handling dynamics by holding the motor rigidly during hard cornering, while maintaining driver comfort during more relaxed driving.

Market and outlook for soft magnetic materials

Over recent years a high level of growth in the soft magnetic materials sector has been witnessed at AMES, reflecting the ongoing development of new applications in the industry. "At AMES there has been a fourfold increase in the turnover from soft magnetic components over the last five years," states Jesús Peñafiel, Director of Marketing for the AMES sintering group. "The future outlook for the production of sintered or composite soft magnetic parts appears to be very bright."

Forecasts for the global magnetic materials market vary, with some analysts predicting a value of $66.6 billion by 2019 [1], others estimate around $33 billion by 2018 [2] and $45 billion by 2020 [3]. These estimates include both soft and hard magnetic materials, but give an idea of the size and importance of the market.

Soft magnetic materials, comprising soft ferrites and electrical steel, represent the largest product segment in the global magnetic materials market. According to one analyst, powder-based soft magnetic products such as soft ferrites and other iron-based powder components are expected to witness growth in the near future mainly driven by the growing demand from end-use industries such as high frequency power electronics and information technology [2].

The number of papers presented at various conferences clearly shows that there is much activity in the research and development of soft magnetic materials. There have been a number of awards presented by PM industry trade associations recognising the advances in properties and the processing of soft magnetic components.

In the automotive sector the number of opportunities for electromagnetic components in transmission, braking, steering and emission control systems is steadily increasing and, with the advantages of net-shape production and the great range of soft magnetic materials available in powder form, the PM sector is well-placed to take advantage of this.

Author

Dr Mark J. Dougan
Chief Metallurgist, Dept. R&D
AMES SA
Camí de Can Ubach, 8
Pol.Ind. "Les Fallulles"
08620 St Vicenç dels Horts
Barcelona
Spain
Tel: +34 93 656 1400
Email: mjdougan@alme.ames.es

References

[1] Soft Magnetic Materials - Technologies, Materials, Devices, New Developments, Industry Structure And Global Markets, Innovative Research and Products Inc, March 2014

[2] Magnets and Magnetic Materials - Global Strategic Business Report, Global Industry Analysts, August 2014

[3] Magnetic Materials Market by Type (Soft and Permanent Magnetic Materials) and by Application (Industrial, Electronics, Automotive, Paints & Coatings, Industrial, Energy Generation, Aerospace & Defense, and Others) - Global Trends & Forecasts to 2020, Markets and markets, September 2015

EURO PM2015 congress & exhibition

Sintering in Powder Metallurgy: Selection of sintering tray material for improved part quality

The choice of sintering tray material is important for any Powder Metallurgy production facility. The selection of tray material composition should go beyond purchase price and incorporate thermal performance and resultant part quality to completely understand the return on investment for each option. In this article, Kirk Rogers and Jon Leist of Carlisle Brake & Friction, USA, highlight the available options and explain the advantages of using carbon-carbon composite materials.

The three most common tray materials in the sintering industry are carbon-carbon composite, extruded graphite and ceramic. The choice of material can depend on the type of products being sintered as well as the physical properties and performance required. In the Powder Metallurgy industry the word ceramic is often used to describe various purity grades of alumina, as well as cordierite body ceramic trays. Many key parameters for alumina, such as specific gravity, specific heat capacity, thermal shock resistance, fracture toughness and thermal conductivity, are similar for cordierite, so statements regarding alumina are generally applicable to cordierite as well. For the purposes of this article, the generic term ceramic will be used to represent this group of materials.

Carbon-carbon composite refers to a composite of carbon fibres with a carbon matrix, essentially fibre-reinforced graphite, and this material is growing in importance in the industry (Fig. 1). The typical physical properties of carbon-carbon composite, extruded graphite and ceramic materials can be seen in Table 1.

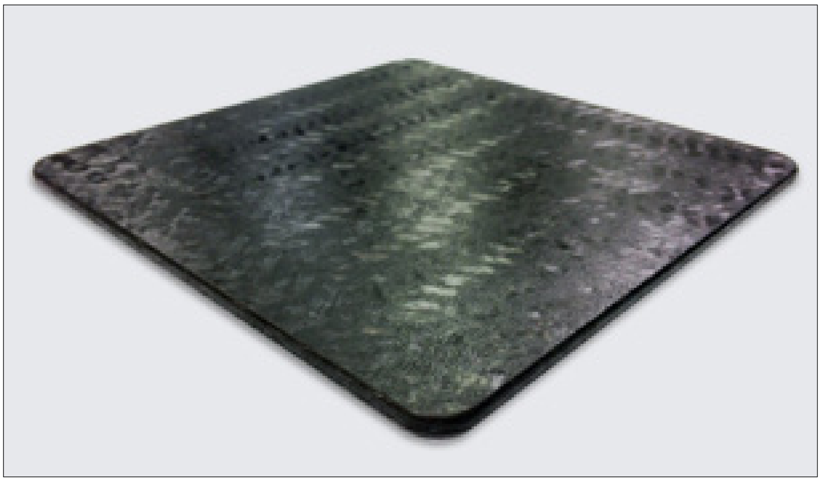


Fig. 1 Carbon-carbon composite sintering trays can offer many advantages to the industry

Tray Properties	Extruded Graphite	Ceramic	Carbon-Carbon Composite (Carlisle HL grade)	Units (SI units)
Specific gravity	0.063 (1.74)	0.105 (2.91)	0.059 (1.63)	lb/cu-in (g/cc)
Weight (11"x20")	5.2 (2.35)	8.7 (3.93)	2.6 (1.18)	lb (kg)
Specific heat capacity	0.31 (1.30)	0.21 (0.88)	0.31 (1.30)	BTU/lb/°F (kJ/kg/K)
Heat capacity	1.06 (2.01)	1.19 (2.27)	0.53 (1.01)	BTU/°F (kJ/K)
Thermal conductivity	50.0	2.3	50.0	W/m-K
Coefficient of thermal expansion	3.5 [RT-200°C]	8	1 [RT-1000°C]	x10^{-6}/°C (x10^{-6}/K)
Fracture toughness	1.4	3.5	43	MPa-m$^{1/2}$
Thermal shock parameter	98.1	0.8	115.4	n/a

Table 1 Physical properties of tray materials

Implications of tray material choice

The product of specific heat capacity and weight is heat capacity, a measure of how much thermal energy must be input or removed to raise or lower the temperature of the material. During the delubrication of compacted parts a lower tray heat capacity enables trays to reach temperature more quickly. This allows compacted parts to reach delubrication temperature earlier which is critical for complete removal of lubricating additives [1].

Heat capacity is also vital during the cool down of sintered parts. Tray materials with high heat capacity may have variations in temperature between the top and bottom of the tray, which can lead to variations in the microstructure, hardness or dimensional stability of parts being sintered on the tray. In order to assess the effect of the thermal properties of tray materials, Carlisle Brake & Friction developed a thermal model that will be presented in this article.

Tray Material	Parts Throughput [kg/hr]	Parts Throughput [kg/hr]	Parts Throughput [kg/hr]	Parts Throughput Increase (%)	
Ceramic	90	336	1,814,000	–	
Graphite	54	372	2,010,000	11%	over ceramic
C/C Composite	27	399	2,152,000	19%	over ceramic

Table 2. Throughput implications of reduced tray weight [2]

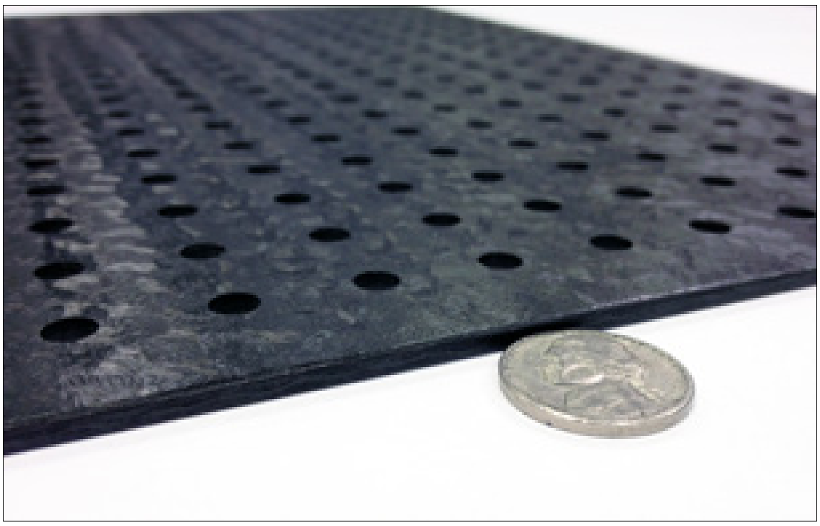


Fig. 2 Thin, fracture tough carbon-carbon composite tray compared to a US Nickel coin

Weight limitations

Tray material choice can also impact on the output capability of the sintering furnace due to weight limitations on wire mesh belts. Furnace operators must balance this constraint against the need for the highest throughput possible. Often, trays of parts are staged with a gap between them or the number of parts on each tray is reduced in order to reduce areal weight on the belt.

A different approach to this limitation is to reduce the weight of the tray itself so that additional parts can be processed. In Table 2, the tray weight throughput in a model furnace [2] is shown for a number of tray scenarios. As tray weight throughput decreases, part weight throughput increases.

Durability

The longevity of tray materials can also be a factor in material choice. Ceramic trays are, by nature, brittle and often fracture during processing due to uneven thermal or mechanical

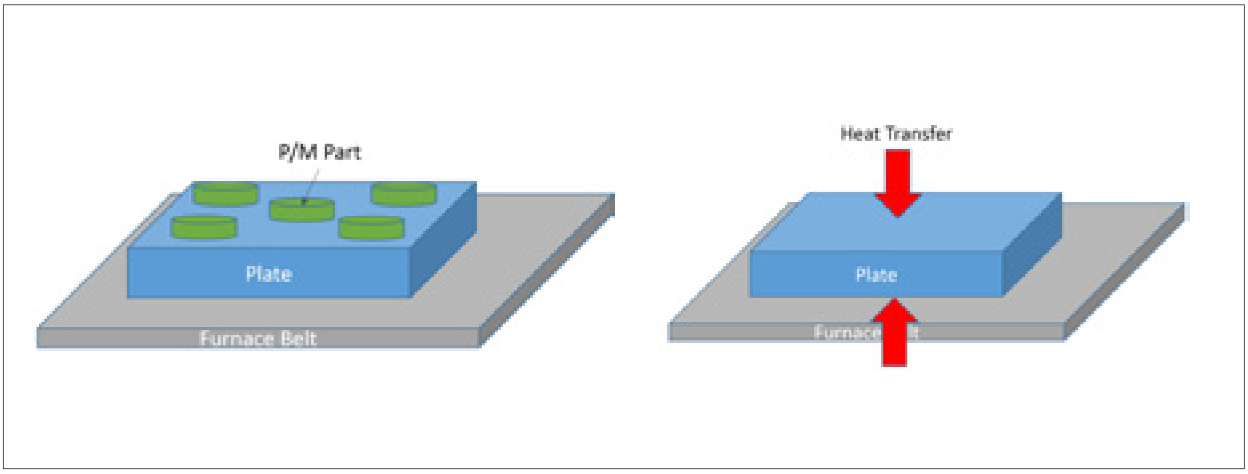


Fig. 3 PM tray typical (left) and simulation setup (right)

loads, stemming from temperature and loading non-uniformity. Handling care during loading and unloading of PM parts may also be an issue.

Graphite trays do not exhibit this failure mode, due to a larger thermal shock parameter (as shown in Table 1), but the material lacks the fracture toughness to survive major handling failures such as dropping. Carbon-carbon composite trays, on the other hand, can be very durable. In one installation of such materials, a customer has cycled trays through the sintering furnace more than 2000 times without a failure (1121°C sintering; dissociated ammonia).

The more common failure mode for graphite and carbon-carbon trays is sliding wear during part placement and removal or loss of carbon into the sintering environment, leading to a non-flat condition. This out-of-flatness can usually be accommodated by an occasional grinding back to the required tolerance.

Type of PM part being sintered

In carbon-sensitive applications, such as soft magnetics, stainless steel formulations, as well as pure iron and low carbon steels (F-0000 to F-0008), the most common tray material choice is ceramic due to a lack of reaction between ceramic trays and sensitive PM parts. However, ceramic trays may contain silica binder that can leach out from the trays under certain dew point conditions, combine with carbon generated by incompletely de-lubed parts and attack the muffle and belt [3, 4] as well as depositing on other furnace internal surfaces. As silica binder leaves the alumina tray its fracture toughness is further reduced, leading to shortened life.

Carbon-based trays generally require eutectic barrier coatings, such as boron nitride or flame sprayed alumina [5] in order to be used with these PM materials. Unfortunately, there is a thermal mismatch between thermally sprayed coatings and the tray material, which, over several thermal cycles, causes coatings to spall and require a recoat. The lifetime of these coatings on graphite is typically around thirty furnace cycles [5], whereas up to 180 cycles have been observed on carbon-carbon composite trays [8]. Other barrier materials have been investigated [6-8] and are used in some portions of the PM and heat treating industries. In all cases of commercial barrier coatings that the authors are aware of, recoating is required frequently, incurring a significant labour investment.

A more permanent solution to the eutectic problem with carbon-based trays is desired by the industry and several high temperature carbide and oxide systems are being actively investigated [9]. Based on that screening work, coatings are currently being produced in volume for evaluation in a production PM sintering environment with several common compositions.

"The lifetime of these coatings on graphite is typically around thirty furnace cycles, whereas up to 180 cycles have been observed on carbon-carbon composite trays"

Comparing tray materials

Numerical simulation

A numerical simulation of the heat transfer environment in a sintering belt furnace was constructed in order to compare the tray materials. The sintering furnace environment used for the purpose of simulation is a large isothermal chamber, which has already reached the sintering temperature and is unaffected by entry of the sintering tray (Fig. 3). While this may be a greatly simplified furnace model, it simplifies the calculations required and allows the tray performance to be evaluated.

Parameter	Graphite Tray	Ceramic Tray	C/C composite Tray
Length, mm (in)	508 (20)		
Width, mm (in)	280 (11)		
Thickness, mm (in)	9.5 (0.375)		5.1 (0.20)
Emissivity	0.8	0.6	0.8
Convection coefficient	100 W/m²/K		
Heating Simulation			
Tray initial temperature	93°C (200°F)		
Sintering temperature	1150°C (2102°F)		
Cooling Simulation			
Tray initial (sintering) temperature	1150°C (2102°F)		
Cooling zone temperature	180°C (356°F)		

Table 3 Simulation parameters

Graphite tray	Ceramic tray	C/C composite tray
18.5	48.2	9.8

Table 4 Time required for centre of tray to reach 1100°C on heating (s)

Graphite tray	Ceramic tray	C/C composite tray
462	512	349

Table 5 Centre of tray after 90 seconds of cooling time (°C)

Central evaluation

For the purposes of this work a standard 508 x 280 mm tray was used that is in production for several customers. As the tray is very large in X and Y dimensions relative to its thickness, only a 1D heat transfer model is required to calculate temperatures near the tray centre accurately. Upon heating to sintering temperature, the tray centre is likely to be the last region to reach sintering temperature, so this is the most relevant portion to evaluate.

The tray is simulated as a half plate down the centreline, with symmetry between the two sides. A further simplification of the sintering environment, made to simplify calculation, was to limit the impact of the sintering belt. Neither conductive heat transfer from the belt to the tray, nor the area shielding of the belt for radiative heat transfer, was considered. Instead, symmetric heating from top and bottom of the tray was coded. Note also that the PM parts are not considered in this simulation, as the part geometry and loading are greatly variable in industry practice.

The applied assumptions were consistent throughout each material and model result and therefore the limitations of the simplified model should not significantly alter the resultant trends. Validation of the model with thermocouples in a block of material travelling through a production PM furnace is ongoing.

Assuming hemispherical, broad radiative spectrum heat transfer, we used a discrete time step model to simulate heat change in each of ten thickness elements in the tray for each time step using a simple Fourier equation model,

$$q = k\,(T1 - T0)/y$$

Where q is the heat flux, k is thermal conductivity of the transport medium and y is the distance between layers of the tray. The maximum temperature change between time steps is calculated such that the model stays stable, then 30000 time steps are computed, which is approximately the first 100 seconds of tray heating or cooling. The emissivity of tray materials was estimated from handbook values [10,11] (Table 3).

Heating and cooling

For heating and cooling simulations, a tray was preheated and immediately placed into sintering or cooling conditions respectively. In each case, the tray was assumed to have reached the previous temperature uniformly before changing conditions. The cooling conditions were set to a common tempering temperature for steel PM parts [12]. The tray dimensions, as well as other simulation settings for these materials are provided in Table 3.

Whereas the graphite and ceramic trays are typically used in the industry at 9.5 mm thickness, the superior fracture toughness of carbon-carbon trays enables them to be specified with a reduced thickness of 5.1 mm (as shown in Table 1).

Results of the simulation

The simulation results indicate that carbon-carbon composite tray centres reach 1150°C sintering temperature twice as quickly as graphite trays and nearly five times as quickly as the ceramic trays (Table 4). Also, the temperature profiles reveal a significant difference between the centre and surface temperatures of the ceramic trays due to the low thermal conductivity of the ceramic material (Fig. 4).

At one point, about 20 seconds into the heating cycle, the difference between surface and centre temperatures approaches 400°C. In contrast, the maximum graphite in-tray differential is <80°C and the carbon–carbon in-tray differential is 41°C.

Similarly, the cooling rate is much faster for the carbon-carbon composite tray such that it is more

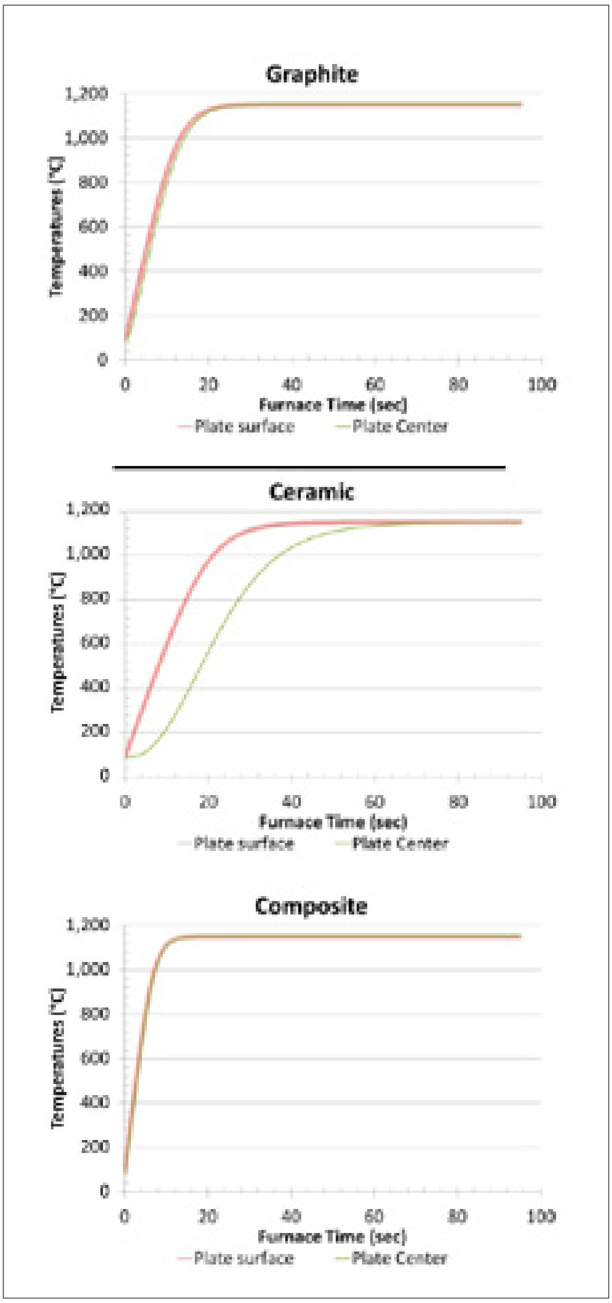


Fig. 4 Calculated heating temperature profiles of the tray materials

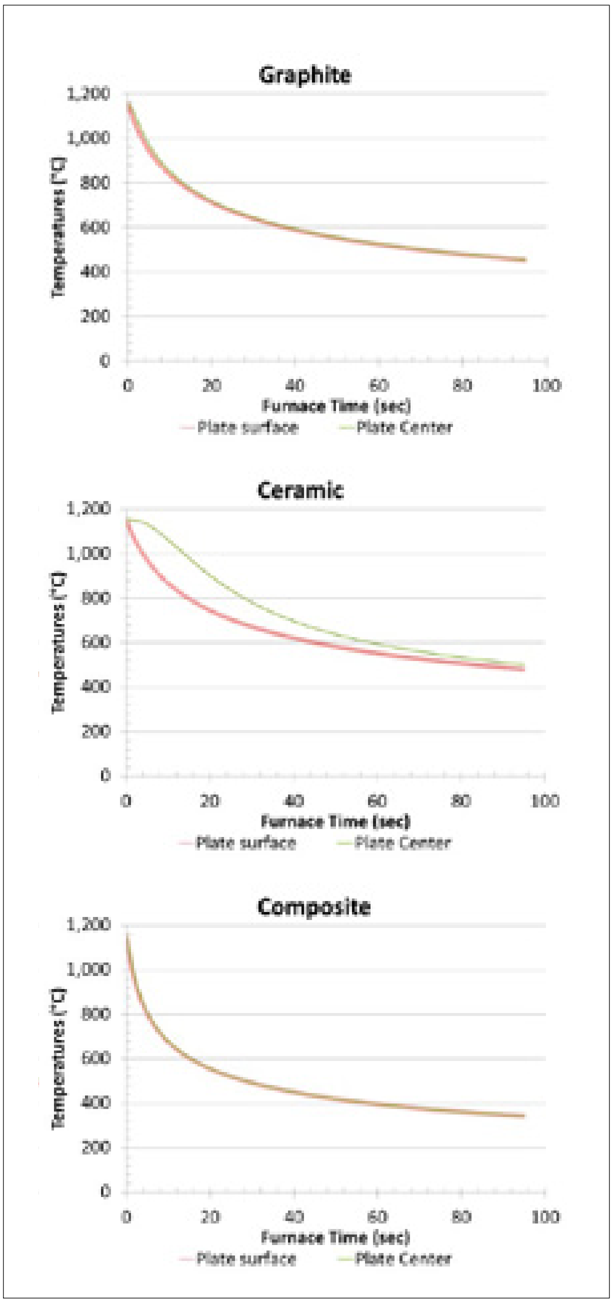


Fig. 5 Calculated cooling temperature profiles of the tray materials

than 100°C cooler than the graphite tray and 150°C cooler than the ceramic tray 90 seconds into the cooling zone (Table 5). The centre and surface temperatures of the ceramic tray also diverge in cooling (Fig. 5).

The best choice of tray material?

Thermal conductivity

The simulation shows that both carbon-carbon and graphite trays reach sintering temperature and subsequently cool to tempering temperature significantly more quickly than ceramic trays. In order of decreasing speed to temperature, tray materials are arranged thus: carbon-carbon > graphite > ceramic.

Delubrication

The ability of the tray to heat and cool quickly can directly impact on part quality in delubrication. Accelerated tray heating allows compacted parts to reach delubrication temperature earlier and time at temperature is critical for complete removal of lubricating additives [1]. Thermal lag, due to higher heat capacity trays, can result in incomplete part delubrication, which can cause a variety of part quality issues such as blistering, sooting, microporosity and carbon segregation.

Heat capacity

Heat capacity is also vital during cool down of sintered parts, especially during sinter-hardening. In order to develop the proper microstructure,

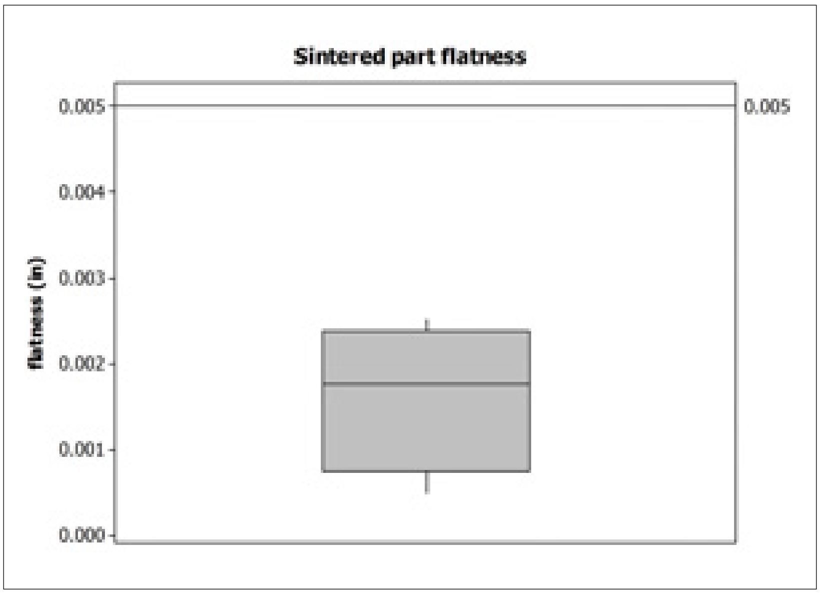


Fig. 6 Boxplot of flatness of example FC-0208 sintered on carbon-carbon composite tray vs specification of 0.005"

a cooling rate adequate to generate martensite must be achieved as the part enters the forced cooling region of the sintering furnace. If the tray retains too much heat, the part will not cool quickly enough and regions of pearlite and bainite may develop instead, resulting in lower than expected hardness. The order of performance for sinter-hardening application based on the thermal simulations above, is: carbon-carbon trays > graphite trays > ceramic trays.

Thermal variation

During sintering, thermal variation due to high heat capacity trays can lead to differences in sintered part microstructure, resulting in varying hardness, sintered density and out-of-flatness. For example, one customer making a 3.175 mm thick FC-0208 part with both narrow and wide cross-sections and a tight flatness tolerance (0.127mm), was running 7-10% scrap on graphite trays. During the initial trial on carbon-carbon trays, the customer had 100% of the product in specification for flatness (Fig. 6) and, according to their VP of Engineering, "we achieved part flatness ranging from .0005" to .0030" [0.0127 mm to 0.0762 mm], which we currently cannot hold with existing plate technology."

The thermal variation computed indicates that during preheat and cooling, graphite trays possess one fifth of the thermal variation of ceramic trays and carbon-carbon trays just one tenth. As high-demand applications such as automotive transmission and engine components require more stringent specifications, dimensional stability over long sintering campaigns is paramount for the industry. This is critical in gear applications where component features interact with one another.

The thermal responsiveness of the tray material chosen has the potential to produce PM parts with reduced dimensional variability that can meet very tight dimensional specifications. In terms of thermal variability, the order of tray choice is: carbon-carbon > graphite > ceramic.

Cost implications of tray choice

Graphite and ceramic trays are typically considered to be part of the maintenance repair and overhaul spend (MRO) budget, while carbon-carbon composite trays can be considered capital equipment tooling due to their longevity and purchase price. Capitalising trays and depreciating them as tooling over five to seven years can have tax advantages as the amount depreciated reduces the effective taxable income in many countries.

Eliminating trays from the MRO spend reduces direct cost of sintering and improves predictability of MRO budgets. Using the cost model we developed in an earlier paper [2] for an FC-0208 composition sintered at 1121°C in a 10% H_2/90% N_2 environment at a belt speed of 15 cm per minute, the direct cost of sintering on ceramic trays is $0.174; on graphite trays it is $0.157; and, on carbon-carbon trays, it is $0.139 per kilo of sintered material. This cost model includes all the typical power and maintenance costs with the exception of the mesh belt, as replacement costs were considered too variable to be included in the comparison.

According to the model, the direct cost of sintering on graphite trays is 10% less than on ceramic, while the cost on carbon-carbon is 21% less than on ceramic and 12% less than on graphite. This process cost reduction allows the high cost of carbon-carbon trays to pay back between one and 14 months, depending on the exact scenario [2], and has the potential to improve the life of the wire mesh belt or increase throughput, which provides additional financial benefits.

Summary

Thermal model results indicate that carbon-carbon trays heat twice as quickly as graphite trays and nearly five times as quickly as the ceramic trays, they cool significantly quicker and have up to ten times the temperature uniformity of ceramic trays during cooling.

This improved thermal performance will lead to improved de-lubrication, a more uniform sintered density, better part dimensional control and improved part flatness. For most sintering applications the order of performance for the three tray materials compared was shown as being carbon-carbon, followed by graphite and then ceramic.

Use of carbon-carbon and graphite trays can reduce the cost of sintering by 10% and 21% respectively over ceramic trays, while allowing throughput increases. However, ceramic trays are less reactive with some compositions. This advantage may soon be diminished, as commercial-scale eutectic coating reaction testing is imminent. Successful demonstration of the durability and reactivity of these coatings will enable the thermal advantages of graphite and carbon-carbon trays to be more widely utilised in the PM industry. Validation of the thermal model is ongoing and publication of the results is forthcoming.

Authors

Kirk A. Rogers, Jon R. Leist
Carlisle Brake & Friction – Carbon Group
Solon, OH 44139 USA

Brian Baddorf
Carlisle Brake and Friction – Hydraulic Group
Solon, OH 44139 USA

Contact: Jon R. Leist
Email: jleist@carlislecbf.com

References

[1] R. Powell, C. Stringer, and S. L. Feldbauer, "Ongoing Investigation of Lubricant Transport within a Powder Metal Compact during Pre-Sinter," Advances in Powder Metallurgy & Particulate materials - 2014, Proceedings of the PM2014 World Congress on Powder Metallurgy & Particulate Materials, May 18-22, Orlando, Florida. MPIF, 2014.

[2] J. R. Leist, J.M. Medina, "Carbon/ Carbon Trays for Reduced Operating Cost of Sintering Furnaces," Advances in Powder Metallurgy & Particulate Materials – 2014, Proceedings of the PM2014 World Congress on Powder Metallurgy & Particulate Materials, May 18-22, Orlando, Florida. MPIF, 2014

[3] A.J. Eckel, N.S. Jacobson, A.K. Misra, D.L. Humphrey, "Hydrogen-Silicon Carbide Interactions," NASA Technical Memorandum 102382, 1989.

[4] N.S. Jacobson, J.L. Smialek, D.S. Fox, "Durability of Silica-Protected Ceramics in Combustion Atmospheres," NASA Technical Memorandum 112171, 1995.

[5] "Rokide in the Powder Metal Industry", Saint-Gobain Ceramic Materials, http://www.coatingsolutions.saint-gobain.com/uploadedFiles/SGcoatingsolutions/Documents/Rokide/Rokide-Powder-MetalIndustry.pdf/

[6] R. Drehmann, C. Rupprecht, B. Wielage, T. Lampke, M. Gilbert, V. Uhlig, and D. Trimis, "Thermally sprayed diffusion barrier coatings on C/C light-weight charging racks for furnace applications," Surface and Coatings Technology 214 p144-152 (2013).

[7] T. Lampke, R. Drehmann, C. Rupprecht, D. Trimis, M. Gilbert, V. Uhlig, "Combined Diffusion Barrier and Wear-Resistant Thermal Spray Coatings on Light-Weight Charging Racks in Furnace Applications," Thermal Spray 2012: Proceedings from the International Thermal Spray Conference and Exposition, May 21–24, 2012, Houston, Texas, USA R.S. Lima, A. Agarwal, M.M. Hyland, Y.-C. Lau, C.-J. Li, A. McDonald, F.-L. Toma, editors. ASM International, 2012.

[8] J.R. Leist, D.R. Snyder, "Barrier Coating Development for Carbon/ Carbon Composite Sintering Trays", presented to Center for Powder Metallurgy Technology, October 2013.

[9] K. A. Rogers and J. R. Leist, "Progress on the Development of Low Cost Environmental Barrier Coatings," Poster presented at Carbon Fibers and Their Composites, April 16-17, 2015, Oak Ridge, TN.

[10] D.R. Poirier, G.H. Geiger, Transport Phenomena in Materials Processing, The Minerals, Metals & Materials Society, Warrendale PA, 1994.

[11] Perry's Chemical Engineers Handbook, 7th Edition, R. H. Perry, D. W. Green editors, McGraw-Hill, 1997.

[12] Material Standards for PM Structural parts, 2009 Edition, Metal Powder Industries Federation, Princeton, NJ USA, 2009.

POWDERMET2015: North America's Powder Metallurgy industry continues on growth track

The North American Powder Metallurgy industry is benefiting from the continued growth of the automotive industry. However, changes to the nature of that sector, with the move to smaller, lighter power units, are proving both a threat and an opportunity. MPIF President, Richard Pfingstler, gave an update of the North American PM industry and looked at trends in the automotive sector at POWDERMET2015, San Diego, USA, May 18 2015.

In his state of the PM industry keynote presentation at POWDERMET2015, Richard Pfingstler, President of the Metal Powder Industries Federation (MPIF), reported that the North American PM industry continued on its growth track in 2014 and suggested that most indicators signal a repeat performance in 2015. Metal powder producers, equipment suppliers, and PM parts makers can look ahead to favourable business conditions, he added.

In 2014, North American iron powder shipments rose a modest 3.6% to 416,373 short tons (377,727 mt). The PM sector of this total shipments figure increased by almost 4.4% to 376,944 short tons (341,957 mt), as can be seen in Fig. 1.

While iron powder shipments topped 400,000 short tons (362,874 mt) again, Pfingstler stated that the industry must keep in perspective the year 2004 when shipments hit a record 473,804 shorts tons (429,827 mt). Estimated stainless steel, copper, aluminium, nickel, molybdenum, tungsten, and tungsten carbide powder shipments grew in 2014 as follows: stainless steel 7,850 short tons (7,121 mt); copper 17,500 short tons (15,876 mt); aluminium 40,000 short tons (36,287 mt); nickel 6,000 short tons (5,443 mt); molybdenum 1,940 short tons (1,759 mt); tungsten 3,600 short tons (3,265 mt); tungsten carbide 5,900 short tons (5,352 mt). Total estimated metal powder shipments in 2014 increased by 3.4% to 499,213 short tons (452,878 mt), as shown in Table 1.

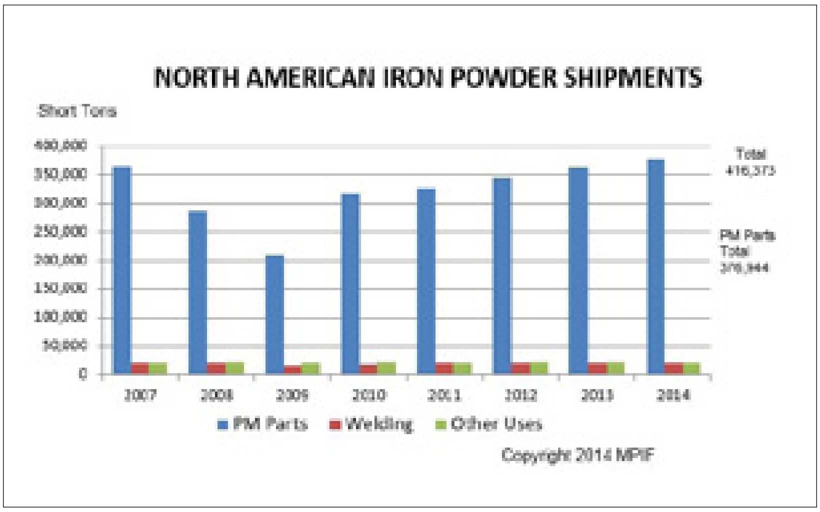


Fig. 1 2014 North American iron powder shipments (Courtesy MPIF)

North American metal powder shipments				
	2013		2014	
Iron & Steel	401,738		416,373	
Stainless Steel	7,600	(E)	7,900	(E)
Copper & Copper Base/Tin*	16,850	(E)	17,500	(E)
Aluminium	37,000	(R)	40,000	(E)
Molybdenum	2,050	(E)	1,940	(E)
Tungsten	4,200	(E)	3,600	(E)
Tungsten Carbide	7,700	(E)	5,900	(E)
Nickel	5,775	(E)	6,000	(E)
Short tons	482,913		499,213	

(E) Estimate (R) Revised estimate *PM parts only

Table 1 North American metal powder shipments (Courtesy MPIF)

The PM equipment market

Pfingstler stated that, overall, PM process equipment builders and tooling makers enjoyed a good year in 2014. PM parts fabricators are ordering new equipment for both capacity increases and added capability, including more robotics and automation for both compacting presses and sintering furnaces.

There continues to be a strong trend for larger compacting presses over 500 tons, along with presses with more motions. Press shipments seem to be stabilising at about 20 units annually, he stated. In 2013 press shipments rose to 26 presses, with a backlog of nine presses. In 2014 shipments declined to 19 presses, with a backlog of 11 presses at the end of the year.

Tooling orders remain positive. One major tooling company sees a growing market for helical gears and a demand for finer and tighter dimensions, especially on punch faces, at +/-10 microns after milling and polishing.

PM parts makers, large and small, are upgrading equipment. For example, one major firm is phasing out older equipment in favour of new CNC equipment and is considering acoustic blending equipment to achieve more homogeneous powder mixes. Another smaller, family-owned business will spend $3.5 million on new equipment. These are positive signs reflecting the industry's health and boding well for future growth.

"There continues to be a strong trend for larger compacting presses over 500 tons, along with presses with more motions."

Current conditions and business outlook

"Emerging from another good year, PM parts companies entered 2015 confident about positive growth indicators on the horizon, even spilling over into 2017. A recent survey by the Powder Metallurgy Parts Association reports that two-thirds of the respondents expect business to increase this year," stated Pfingstler.

"Most PM fabricators are doing well, but there are still difficulties finding qualified employees, especially die setters. The industry must do more to attract skilled labour and engineering graduates into manufacturing. MPIF recently participated in career fairs at several universities to increase engineering students' awareness of PM. MPIF staff engaged with nearly 100 students while providing opportunities for possible employment."

"North American iron, copper, and stainless steel powder shipments should be up again in the three-to-four-percent range. Metal powder companies are actively pursuing developmental projects to meet market needs and improve the performance of raw materials through a reduction of lubricants in binder-treated premixes and the use of a new lubricant for stainless steel PM materials. A new generation of high-performance PM aluminium materials is in the wings as well."

A number of key PM parts makers forecast double-digit growth this year in both automotive and industrial markets. For example, new PM clutch designs are taking hold in snowmobiles, snow throwers and all-terrain vehicles. PM's high reliability in high-performance clutches is unquestioned, a welcome sign and an example of the acceptance for PM components that are used under harsh operating conditions.

Tungsten and Refractory Metals

The overall tungsten business faced tough times in the second half of 2014 due to weakening oil prices and mining activity, stated Pfingstler. "Total tungsten powder shipments declined by 14.2% in 2014 to an estimated 3,600 short tons (3,266 mt). Tungsten carbide shipments dropped 23.3% to an estimated 5,999 short tons (5,442 mt). This year will remain rough as well. Oil-and-gas drilling, important markets for tungsten, could drop by as much as 40 to 60%."

The outlook for mining, another well-established market for tungsten products, will remain soft. The only bright spots are automotive and aerospace markets, which unfortunately are not large consumers of tungsten.

MPIF industry technology support

It was stated that the MPIF Technical Board is reviewing the importance of reducing dimensional variability in PM parts and looking at steps to improve dimensional tolerances out of the compacting press. Board members are gathering information about how process factors such as raw materials, compacting, sintering, and secondary operations influence dimensional control. The ultimate goal is to improve the dimensional tolerances of PM parts by 50%. The board is also studying the development of lean alloys.

Pfingstler explained that the Center for Powder Metallurgy Technology (CPMT), with its 52 industry members, leads the investigation of strain-controlled fatigue for numerous PM materials: resonant acoustical processing to enhance powder mixing; sinter-hardening process improvements for flatness and throughput; die-wall lubrication for warm compaction tooling; shot peening of gears for improved performance; and ways to improve tooling to withstand compacting pressures >60 tsi. CPMT is also providing $32,000 in university scholarships through various family and corporate grants and sponsored four students to attend POWDERMET2015 through another family grant.

"Individual PM companies continue funding developmental programs aimed at improved materials and processes to support PM's growth and future viability. Equipment makers, for instance, are designing more robust multi-platen systems in both servo-controlled hydraulic and electrical compacting presses. Higher-strength PM aluminium alloys are being developed that provide yield strengths of 45,500 psi, as are high-density stainless steels >7.4 g/cm3 by single pressing," stated Pfingstler.

Novel R&D programs are being aimed at multiple-scale particulate composites and combining metallic and ceramic properties, for instance, joining the abrasion resistance and rigidity of ceramics with the toughness and electrical conductivity of metals.

"Resilience and creativity are the hallmarks of today's PM industry. Just as it has survived and thrived in the face of previous economic trials,

Fig. 2 MPIF President Richard Pfingstler reviewing the State of the PM Industry

these qualities will help insure that the industry will continue to grow in the face of challenges yet to come," added Pfingstler.

North American automotive trends

Pfingstler cautioned that, whilst there is a positive growth outlook for PM in 2015, with a potential 17.3 million car-year market, certain headwinds might diminish the pace of this growth. "As we reflect on 2004, when iron powder shipments hit a record 473,804 short tons [429,828 mt], we note that North American light-vehicle production was 16.2 million units. In 2014, auto builds advanced to 16.8 million units but iron powder shipments reached only 416,373 short tons [377,727 mt]. A disconnect appears," he stated.

"Several explanations suggest themselves. There is a new paradigm for light-weighting in the automotive industry. Consider the example of the new 2015 Ford F-150 truck, which comes in at a weight of some 700 pounds [318 kg] less than the comparable 2014 model; light-weight components such as its aluminium body panels and high-strength steel ladder-frames come straight from technologies used in the aerospace industry."

"The trend spawned by manufacturers' quest for higher CAFE numbers is toward smaller powertrains, from eight to six and four-cylinder engines, and thus toward fewer and lighter-weight parts - and away from heavy PM bearing caps and powder-forged connecting rods. PM, however, is not alone in feeling this impact: competitive technologies, such as castings, wrought forgings and machined parts, must also pony up to meet rising technological requirements."

"The trend spawned by manufacturers' quest for higher CAFE numbers is toward smaller powertrains, from eight to six and four-cylinder engines"

Pfingstler stated that MPIF recognises this light-weighting trend as an opportunity. As such, MPIF has joined Lightweight Innovations for Tomorrow (LIFT), an industry-led,

Fig. 4 The POWDERMET2015 Gala Dinner was held at the US Marine Corps Air Station at Miramar

government-funded consortium, to help facilitate technology transfer into supply-chain companies. LIFT is one of the institutes launched by the National Network for Manufacturing Innovation. MPIF's move to gain a voice in this $140+ million program is important for our industry.

Another possible explanation for the disconnect between the increased auto builds and the failure of powder shipments to rise to previous levels is that many new engines and transmissions are being designed in Europe and Asia with less PM content. The number of possible PM applications has decreased. "It is said European auto engineers lean towards higher performance over cost and toward closer tolerances. For example, in North America a Class 8 gear is normally acceptable, while European engineers require Class 9 and 10 gears. Meanwhile, a leading German automatic transmission supplier has designed an eight-nine speed transmission for a 'Detroit 3' auto maker that contains only two PM oil-pump parts," explained Pfingstler.

"This trend has had the effect of forcing US parts makers to meet tighter or "Europeanised" tolerance requirements of less than 10 microns across the board. Go to trends for meeting these demands include surface finish grinding, localised hardening, grinding after heat treating and grinding or machining for flatness," commented Pfingstler.

"Focusing on distinct PM product sectors with more value-added operations is another trend involving big name PM auto parts makers. For one specialised automotive parts supplier, adding value through extra machining and other specialised post-processing is enabling the company to book business into 2020; the company is already in discussions about designs for the 2021 model year."

PM content in light trucks amounts to between 25 kg and 27 kg, with the average PM content in light vehicles estimated at 20 kg. This is in marked contrast with the average European vehicle, which in 2014 contained an estimated 9.5 kg of PM parts.

The Metal Injection Moulding (MIM) industry has begun selling into the automotive market in North America, following the trend in Europe towards the adoption of MIM automotive components. "Automotive engineers are designing more MIM parts, which points to significant potential growth as MIM becomes more accepted. MIM parts are being designed for engines, electrical systems and chassis hardware," concluded Pfingstler.

POWDERMET2016

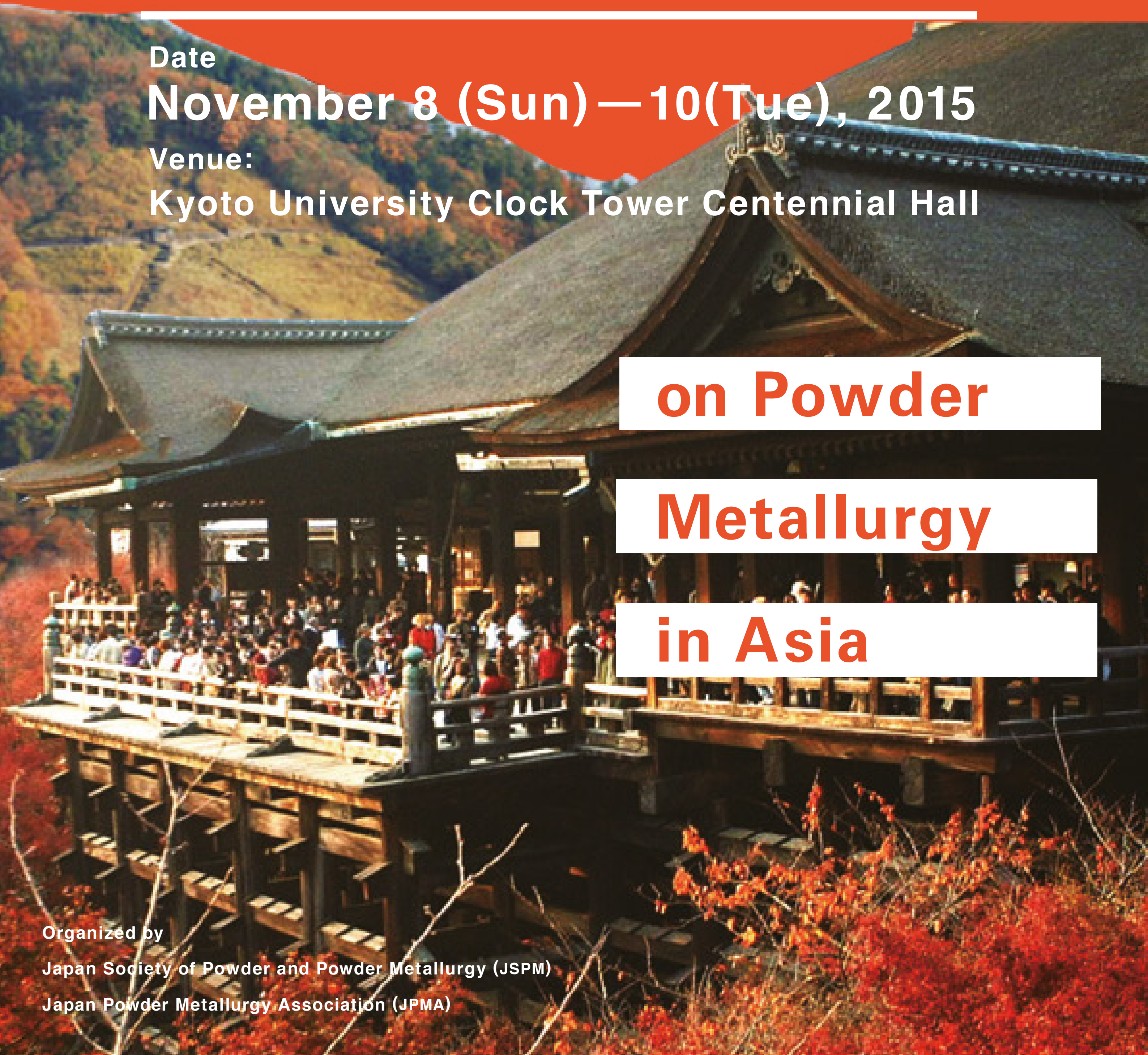
The next event in the MPIF series of annual conferences will take place in Boston, Massachusetts, June 5-8, 2016.

3rd International Conference in Kyoto, Japan

APMA 2015

Date
November 8 (Sun) — 10(Tue), 2015

Venue:
Kyoto University Clock Tower Centennial Hall



on Powder Metallurgy in Asia

Organized by
Japan Society of Powder and Powder Metallurgy (JSPM)
Japan Powder Metallurgy Association (JPMA)

POWDERMET2015: MPIF Powder Metallurgy Design Excellence Awards 2015

Winners of the Metal Powder Industries Federation 2015 Powder Metallurgy Design Excellence Awards competition were announced at POWDERMET2015, San Diego, USA, May 17-20. The annual awards provide a showcase for the industry and demonstrate the ability of Powder Metallurgy technology to meet high tolerances in a wide range of demanding applications.

Winning parts in the MPIF's 2015 Powder Metallurgy Design Excellence Awards competition clearly demonstrated the capability of Powder Metallurgy to offer solutions to key industry sectors. The following is a selection of the awards that are categorised as being manufactured via the conventional press-and-sinter route. Awards manufactured via the Metal Injection Moulding (MIM) process will be reported in our sister publication *Powder Injection Moulding International, Vol 9, No 3, September 2015.*

Grand Prize Awards

Automotive - Transmission

FMS Corporation, Minneapolis, Minnesota, USA, was awarded a Grand Prize in the Automotive - Transmission Category for a thrust washer and two back-up washers made for its customer Allison Transmission (Fig. 1).

The components play a critical role in the function of Allison's new TC10 automatic transmission for Class 8 (18-wheel) tractors. A first of its kind for the trucking industry, this 10-speed automatic transmission enables even inexperienced drivers to achieve 5% fuel savings over typical manual transmissions, thus contributing to a significant lowering of CO_2 emissions.

Fabricated from a proprietary low-alloy steel, the three parts are warm compacted to achieve high

Fig. 1 Thrust washer and two back-up washers made for Allison Transmission by FMS Corporation (Courtesy MPIF)

Fig. 2 Keystone Powdered Metal Company manufactures this rake cam, right-hand and left-hand guides, and an eccentric cam made for its customer Nexteer Automotive (Courtesy MPIF)

Fig. 3 Five conventional PM components are assembled in this planetary gearset from Allied Sinterings, Inc (Courtesy MPIF)

green density, then vacuum sintered at high temperature, gas-pressure quenched and tempered. They are produced very close to net shape, with only precision machining of some surfaces performed to improve the micro-finish as well as for dimensional accuracy. While these washers were an original PM design, they are estimated to save 30% over the cost of comparable forged/machined components.

Automotive - Chassis

Keystone Powdered Metal Company, St. Marys, Pennsylvania, USA, received the Grand Prize in the Automotive - Chassis Category for a rake cam, right-hand and left-hand guides and an eccentric cam, made for its customer Nexteer Automotive (Fig. 2). The diffusion-alloyed steel components are used in Cadillac ATS and CTS, Chevrolet Impala and GM Holden Commodore (Australia) steering columns. They are key elements of the column's tilt and telescope adjustment feature, serving a vital role in maintaining the column's position during a crash event.

The multi-level parts are fabricated to net shape, with in-line heat treatment and tempering being the only secondary operation preformed to ensure the required hardness and strength. The rake cam and guides have features that allow for a mechanical lock of the plastic overmould, in an operation performed by Agapé Plastics, Inc. The economic targets of the customer's preferred design for the steering column tilt/telescope adjustment and lock—with a "pin pocket" that gives a positive detent feel—could be met only with the flexibility offered by PM.

Hardware/Appliances

Allied Sinterings, Inc., Danbury, Connecticut, USA, received the Grand Prize in the Hardware/Appliances Category for five conventional PM components that are assembled in a planetary gearset. The parts, an input flange, output flange, planet gear, sun gear and ring gear, go into a self-contained single-stage gearset used in high-end lighting-control applications (Fig. 3).

The input and output flanges are made of nickel steel, the planet and sun gears of a low-alloy hybrid steel and the ring gear of a sinter-hardened steel. The assembly is completed using a washer, spacers and dowel pins, easily producible or off-the-shelf items whose use was a specific objective of the gearset design.

Both flanges are produced net shape, requiring no secondary operations. The sun gear is actually designed as a compound gear, with the second gear serving as a spline for the mandrel. It and the planet gears are heat treated to increase their strength. The lower hardness requirement on the ring gear allows it to be made of a sinter-hardened powder. Tight tolerancing is essential for the gearset's virtually noiseless operation.

Medical/Dental

A sinter-hardened steel planetary gear system, featuring a carrier with an integrated sun gear and three planetary gears, earned the Grand Prize in the Medical/Dental Category for ASCO Sintering Co., Commerce, California, USA.

The system is used in multiple stacks for gear reduction in a single use, portable, physician operated surgical device. In addition to the integrated pinion gear, the carrier includes three posts that extend above the flange with a two-to-one length-to-diameter ratio. Proprietary press mechanisms were required to achieve the post density, as well as a proper post-to-flange bond. The carrier is pressed, sintered and tempered to net shape (Fig. 4).

The part had originally been fabricated as an assembly of a PM part and wrought posts. By integrating the posts to the flange through advanced PM manufacturing techniques and by the elimination of a secondary heat-treating operation through the use of modern sinter-hardening materials, the new part design achieved a 60% cost reduction. The part is an outstanding example of a Powder Metallurgy medical application, unique in that it is not made of stainless steel nor is it fabricated through Metal Injection Moulding.

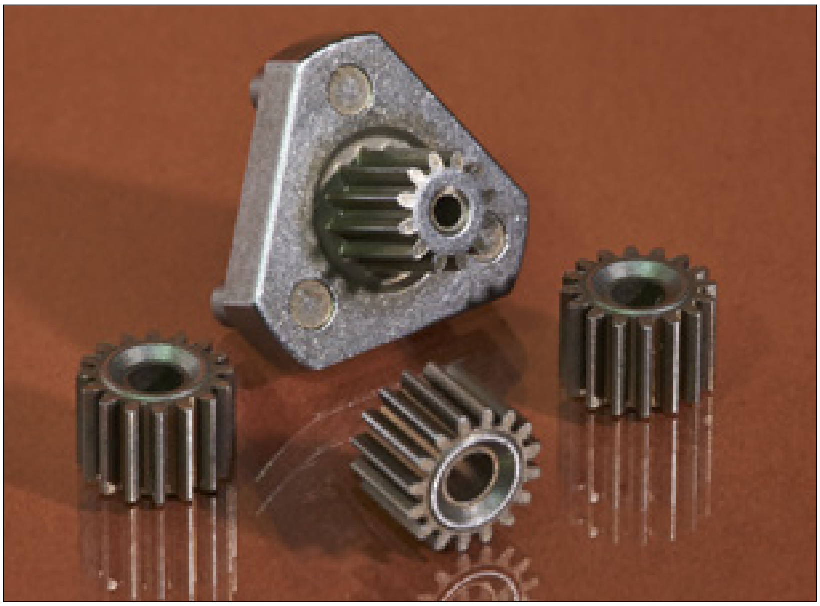


Fig. 4 ASCO Sintering Co manufacture this sinter-hardened steel planetary gear system (Courtesy MPIF)

Awards of Distinction

Automotive - Engine

SMC Powder Metallurgy, Inc., St. Marys, Pennsylvania, USA, won the Award of Distinction in the Automotive - Engine Category for a stainless steel flange made for Kendrion FAS Controls. The component connects and seals a spill valve operating in an automotive fuel system (Fig. 5).

The valve was specially designed for gasoline direct injection technology, facilitating lower fuel consumption and higher efficiency. Replacing a wrought part that required heavy machining, the PM flange is fabricated from a proprietary premix developed in order to achieve the required dimensional stability. The part has a perpendicularity requirement relating to the machined counterbores and O-ring groove.

After compaction, the parts are de-lubed and then placed on specially designed slates for high-temperature sintering in 100% hydrogen. The parts are then resin impregnated to aid in machining and for a mechanical seal.

The customer believes this is the only PM part used in a high-pressure fuel system and it is expected to expand into other platforms. To date, over 1.6 million flanges have been made and shipped to the customer.

Fig. 5 The component connects and seals a spill valve operating in an automotive fuel system from SMC Powder Metallurgy, Inc (Courtesy MPIF)

Fig. 6 Porite Taiwan Co. Ltd., received an award for five components comprising an output gearbox that serves as feedback for an anti-twist lock on a drill driver (Courtesy MPIF)

Hand Tools/Recreation

Porite Taiwan Co. Ltd., Chunan, Miao-Li, Taiwan, earned an Award of Distinction in the Hand Tools/Recreation Category for five components comprising an output gearbox that serves as feedback for an anti-twist lock on a drill driver (Fig. 6). The parts, intermediate flange, anti-twist lock, mount ring, centring sleeve and planet gears, are made from diffusion-alloyed steel. The flange is compacted, using two upper and two lower punches, and powder moving technology is employed to achieve a more uniform density distribution.

Tight tolerances at the inner and outer diameters is accomplished through machining and a milling operation provides the holes needed for part assembly. The parts' design, with extremely thin sections and highly complicated geometries, required precise control by a CNC compacting press. The PM design saved more than 40% over the cost of manufacturing through forging and machining.

POWDERMET2015: Further developments in Hot Isostatic Pressing technology

The growing significance of the use of Hot Isostatic Pressing (HIP) in the processing of powder products was demonstrated by the inclusion of three HIP sessions in the conference programme for POWDERMET2015, held in San Diego, USA, May 17-20, 2015. Dr David Whittaker reports on a selection of the papers included in these sessions.

HIP for mechanical-optical systems

The paper contributed by Amanda Morales and Don Hashiguchi of Materion Beryllium & Composites, USA, [1] focussed on the HIP processing of beryllium and aluminium-beryllium alloys, which are used as light weight, high modulus materials for mechanical-optical systems.

Hot Isostatic Pressing is used in the value stream as a near net shape (NNS) manufacturing process to reduce both material and processing costs. HIP also provides technical benefits for alloys that are challenging to cast because of large differences between liquidus and solidus temperature. Furthermore, HIP consolidated atomised powder produces a fine aluminium-beryllium eutectic free from macro-segregation and results in uniform and isotropic mechanical properties, which is an important consideration in optical systems.

The paper described a methodology for the optimisation of NNS-HIP products called the Seamless Iterative Process (SIP). This process is used to continuously reduce the necessary material to make a part without the need for changes to downstream processing (Fig. 1).

The process begins by designing the SIP blank from a part drawing. This blank will envelop the finished part leaving material stock in all areas, but will incorporate features to provide a more cost-effective piece of material as opposed to a rectangular block (Fig. 2). The finished

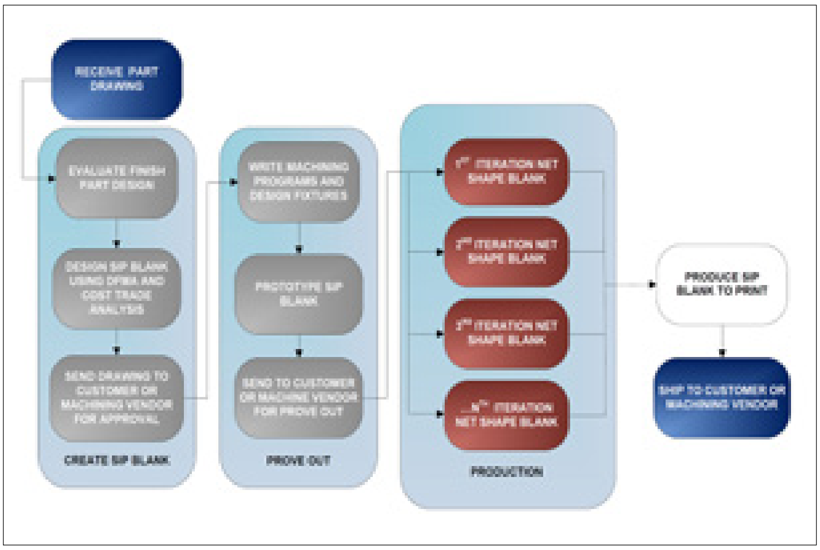


Fig. 1 Flow chart of the Seamless Iterative Process [1]

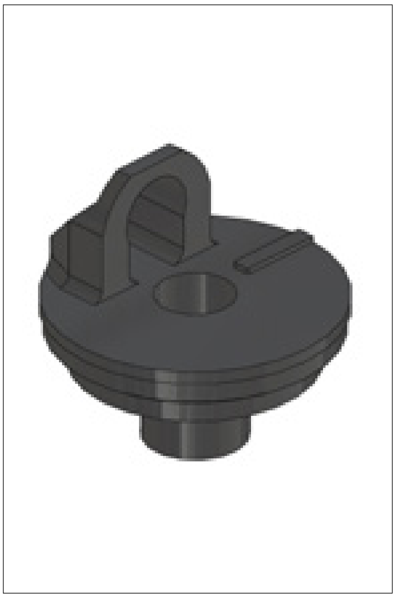


Fig. 2 SIP blank designed from a finished part [1]

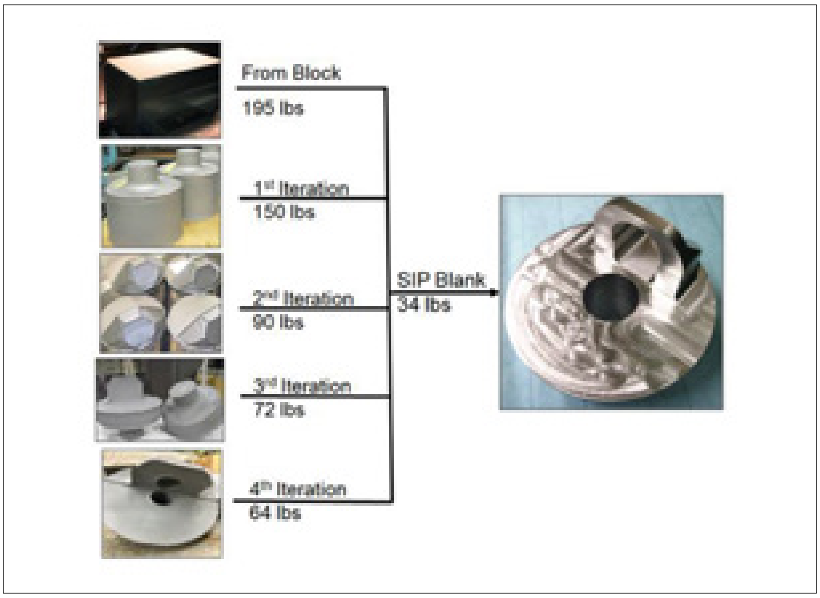


Fig. 4 SIP through four iterations [1]

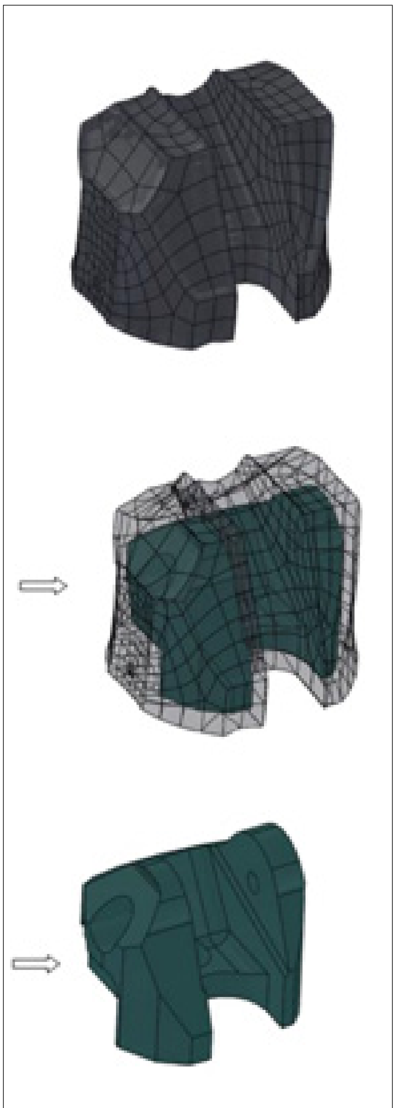


Fig. 3 Non-contact CMM model of post-HIP part to yield SIP blank [1]

part drawing is reviewed and large pockets, through-holes and other features are identified for incorporation into the SIP blank. Other features are identified, which can be easily machined, but which may be incorporated into the HIP can in a later iteration.

Once the SIP blank is approved, prototypes are produced, either by machining from a block or through the development of a low risk first iteration can. Once these prototypes have been demonstrated and approved, parts move into the production phase and the SIP process begins. After each HIP can iteration, dimensions of the solid part are measured manually (with callipers) or with a non-contact (laser) coordinate measuring machine (CMM).

The CMM produces a three-dimensional model (Fig. 3), from which the areas for further dimensional optimisation and the additional features for incorporation in the next can iteration may be determined. Subsequent iterations are continued, as long as the material and processing cost savings outweigh the costs needed to make the changes.

The SIP methodology was demonstrated through a case study (Fig. 4). The SIP blank was originally made from a block requiring 88 kg of aluminium-beryllium alloy. After four can iterations, the required material was reduced to 29 kg, an almost 70% reduction. Machining time was also reduced by around 6 hours.

The presentation concluded with a discussion of other advantages of NNS-HIP over competing manufacturing approaches, in terms of applicability to smaller order quantities and of size range capabilities (HIP beryllium and aluminium-beryllium allows for monolithic parts varying in size from 9 to 455 kg).

Reinforced aluminium Metal Matrix Composites

Don Hasiguchi presented a second paper on behalf of his co-authors Jeffrey Campbell and Charles Pokross, Materion Beryllium & Composites, USA, and David Tricker and Andrew Tarrant of Materion Aerospace Metal Composites, UK [2]. This paper described the development of technology for the extrusion of discontinuously reinforced aluminium Metal Matrix Composites (MMCs).

Aluminium MMCs are engineered materials that can achieve high strength, high specific modulus and relatively low thermal expansion when compared with base aluminium alloys. There are several means of making aluminium MMCs, including stir-casting, rolling, liquid metal

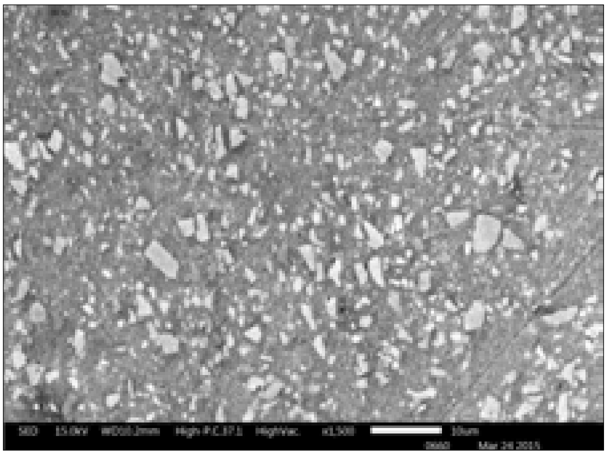


Fig. 5 SEM image of a polished cross-section of a mechanically alloyed powder particle containing 25% SiC in a 2124 aluminium matrix (2124/SiC/25p). The distribution of SiC particles is uniform within the powder particle even before consolidation [2]

Fig. 6 Two shapes extruded through porthole dies made from 6061/SiC/20p aluminium MMC. One shape is 62 mm H x 50 mm W x 1.8 mm wall; the other shape is 50 mm H x 44 mm W x 1.8 mm wall with a 30 mm projected fin [2]

penetration, pre-mixed powder and high energy milling.

The material reported in this paper utilised a proprietary high energy Powder Metallurgy or mechanical alloying process to produce a homogeneous distribution of SiC reinforcement within the aluminium alloy matrix. Inert gas atomised aluminium powder was mechanically milled with SiC powder, with a mass median particle size (d50) controlled from 3 µm to 0.3 µm. The milled powder was then consolidated by HIP and subsequently extruded into mill product forms. Mechanical alloying confers a number of advantages:

- The energy input allows the use of finer SiC particles, together with a higher powder loading
- The particles produced are somewhat analogous to atomised powders in that each powder particle contains a uniform distribution of SiC within each "composite powder particle" (Fig. 5). This produces a uniform MMC microstructure
- A relatively high particulate loading with uniform distribution and high reinforcement/matrix adhesion is achievable compared with alternative processes. Porosity is not observed after consolidation of the composite powder particles.

The ability to combine finer particulate size, high ceramic loading and, therefore, shorter mean free path between particles can produce higher strength and high modulus materials. The finer particle size is a key enabler in reducing the cost of downstream manufacturing.

Two types of extrusion process have been applied to HIP-consolidated billets; bulk extrusion to form rod, bar, tube and shapes that are extruded in a single metal stream and precision extrusion made through a porthole or bridge die, in which a cylindrical billet separates at the die entry and then re-welds into a hollow shape before exiting the die. The company has developed bulk extrusion product forms, using a conventional horizontal press with 3,000 ton press stem capacity. Some of the extruded product forms include flat bar, rods and simple shaped geometries.

Precision or bright extrusion of Al-SiC shapes (Fig. 6) has made use of a porthole die. Precision extrusion techniques are preferred with 6xxx series aluminium alloys to allow the use of high throughput commercial extrusion

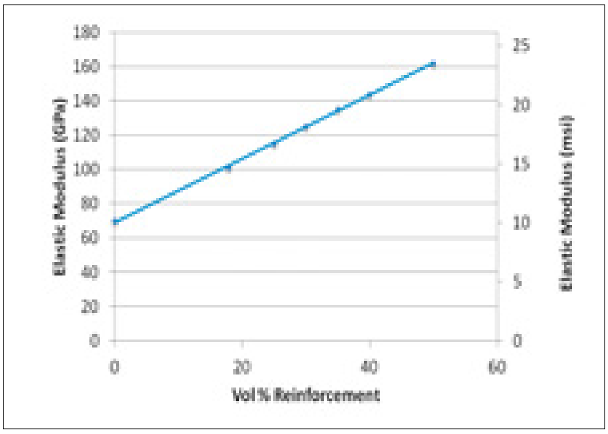


Fig. 7 Elastic modulus as a function of SiC particle loading in an aluminium alloy matrix [2]

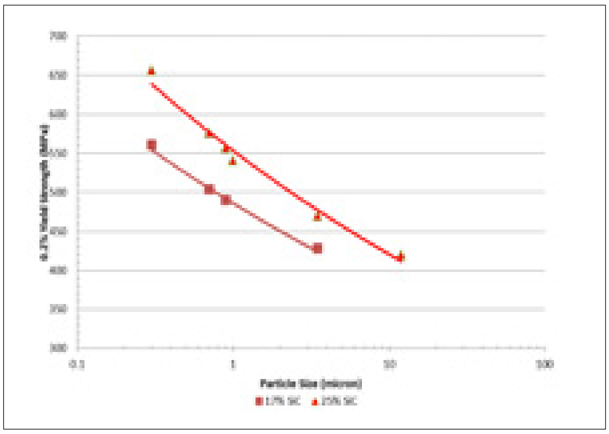


Fig. 9 Effect of SiC particle size and % loading on strength. Development of finer sub-micron SiC particulate and higher loading increases 0.2% Yield Strength [2]

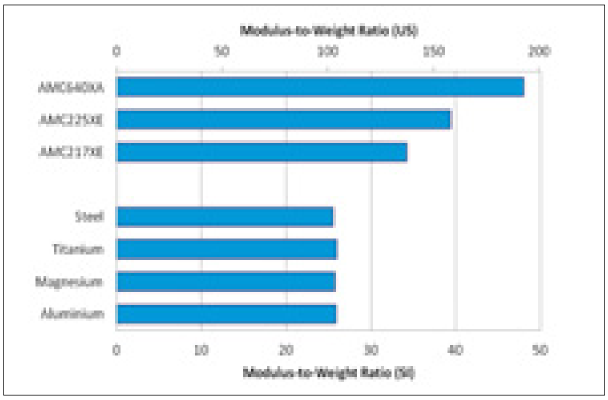


Fig. 8 Specific modulus as a function of %SiC loading. The MMC designation codes are explained in Table 1 [2]

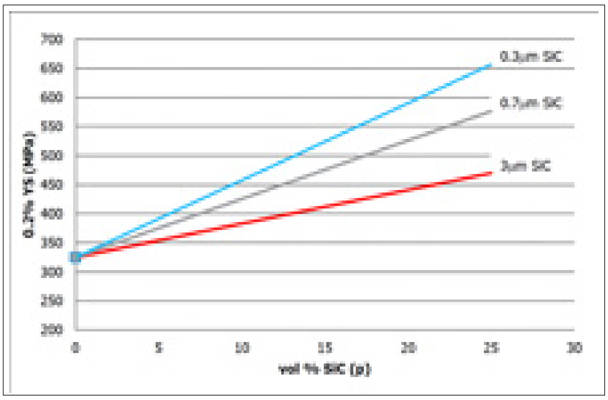


Fig. 10 Yield Strength as a function of % particulate loading and SiC particle diameter [2]

Product Form	Extruded Al6061	HIP'd AMC225xe	Extruded AMC217xe	Extruded AMC225xe	Extruded AMC640xa
Equivalent		2124/SiC/25p	2124/SiC/17p	2124/SiC/25p	6160/SiC/40p
Average SiC size (micron)	-	3	3	3	3
Orientation	L	Isotropic	L	L	L
Temper	T6	T4	T4	T4	T6
0.2% YS – MPa (ksi)	275 (40)	455 (66)	420 (61)	480 (70)	490 (71)
UTS – MPa (ksi)	310 (45)	570 (83)	620 (90)	680(99)	620 (90)
Elongation (%)	12	2	8	5	2.5
Modulus – GPa (Msi)	70 (10.2)	115 (16.7)	100 (14.5)	115 (16.7)	140 (20)
CTE 25C to 100C – ppm/C (ppm/F)	23 (12.7)	15.5 (8.6)	16.8 (9.3)	15.5 (8.6)	13.4 (7.4)

Table 1 Typical properties of extruded aluminium AL-SiC MMC's [2]

presses. Use of the mechanically milled input Al-SiC material, with a uniform dispersion of fine reinforcement particles, allows the weld to form during the extrusion process, an issue that would be problematic with larger diameter particles.

The paper continued with an analysis of the mechanical properties achievable in the extruded MMC products. Increasing the SiC particulate loading in MMC compositions increases the modulus of the material (Fig. 7). As SiC is denser than aluminium alloys (around 3.2 g/m^3 compared with around 2.7 g/m^3), higher particulate loadings increase the density of the composite; nonetheless, Al-SiC composites have a high specific modulus (modulus per unit volume) compared with other structural materials (Fig. 8).

Typical mechanical properties and CTE of extruded Al-SiC MMCs are shown in Table 1 and are compared with Al6061, a common structural aluminium alloy. Higher strength and lower ductility is seen for Al-SiC MMCs compared with Al6061. Low or controlled CTE can be an important property in applications with temperature excursions, such as combustion engines, brakes and electronic substrates. Higher particle loading decreases CTE.

A HIPped version of 2124/SiC/25p is shown in the second column of Table 1 and may be compared with the same MMC composition in its extruded form in the third column. Extrusion of Al-MMCs produces a textured microstructure and, most likely, higher mechanical properties in the longitudinal direction.

Development work is continuing to utilise and process finer SiC particles. Current grades offered commercially contain either 3 µm or 0.7 µm SiC particles and property characterisation of Al-MMCs produced with 0.3 µm particles is underway. As an example, it is emerging that 0.2% Yield Strength increases significantly with a finer 0.3 µm SiC particle diameter as with higher volume loading (Figs. 9 and 10).

A summary of the properties for the 2124/SiC/17p (0.3 µm) and the 6061/SiC/20p (0.7 µm) is shown in Table 2, illustrating the higher strength with finer SiC particle size compared with the 2124/SiC/17p (3 µm) composition in Table 1.

Applying aluminium cladding to nuclear fuel plates

The theme of the incorporation of HIP as one element within a wider manufacturing strategy was continued in a paper from K D Clarke and colleagues at Los Alamos National Laboratory, USA, which assessed the use of HIP as a means of applying aluminium cladding to LEU-10 wt% molybdenum monolithic nuclear fuel plates [3].

The US Department of Energy National Nuclear Security Administration (DOE/NNSA) has a reactor conversion programme that aims to reduce or eliminate the use of highly enriched uranium (HEU) dispersion fuels in high-performance research reactors and replacing the fuel with low enriched uranium (LEU).

Simply substituting LEU for HEU in existing fuel designs would not meet the uranium loading requirements to operate these reactors. To maintain performance requirements, DOE/NNSA is developing high density monolithic fuel plates that contain low-enriched uranium-10wt% molybdenum (U-10Mo) foils coated with zirconium and clad with 6061 type aluminium. The probable processing route for these fuel plates includes HIP to bond the aluminium cladding to the fuel foil and to itself.

Initial proof-of-concept HIP trials were performed at Idaho National Laboratory (INL) on approximately 1/10 to 1/5 scale mini fuel samples. The HIP can was designed to contain a stack of alternating strong-backs (flat steel plates used to separate, transfer uniform stress and ensure flat fuel plates) and fuel plate layers (including the fuel foil and aluminium cladding material), along with a

Product Form	Extruded Al6061	Extruded AMC217xg	Extruded AMC620xf
Equivalent	-	2124/ SiC/17p	6061/ SiC/20p
Mean Sic Size (micron)	-	0.3	0.7
Orientation	L	L	L
Temper	T6	T4	T4
0.2% YS – Mpa (ksi)	275 (40)	545 (79)	380 (55)
UTS – Mpa (ksi)	310 (45)	670 (97)	470 (68)
Elongation (%)	12	7	8
Modulus – Gpa (Msi)	70 (10)	100 (14.5)	103 (14.9)

Table 2 Typical properties of extruded aluminium MMC with finer SiC particle size [2]

parting agent to allow the aluminium-clad fuel plates to be separated from the strong-backs after HIP processing. These initial trials demonstrated that, with the addition of a co-rolled zirconium diffusion barrier on the U-10Mo fuel foil, the HIP bonding is a potentially viable method of producing monolithic fuel plates.

Further work at Los Alamos National Laboratory (LANL) then scaled-up the can design to produce large

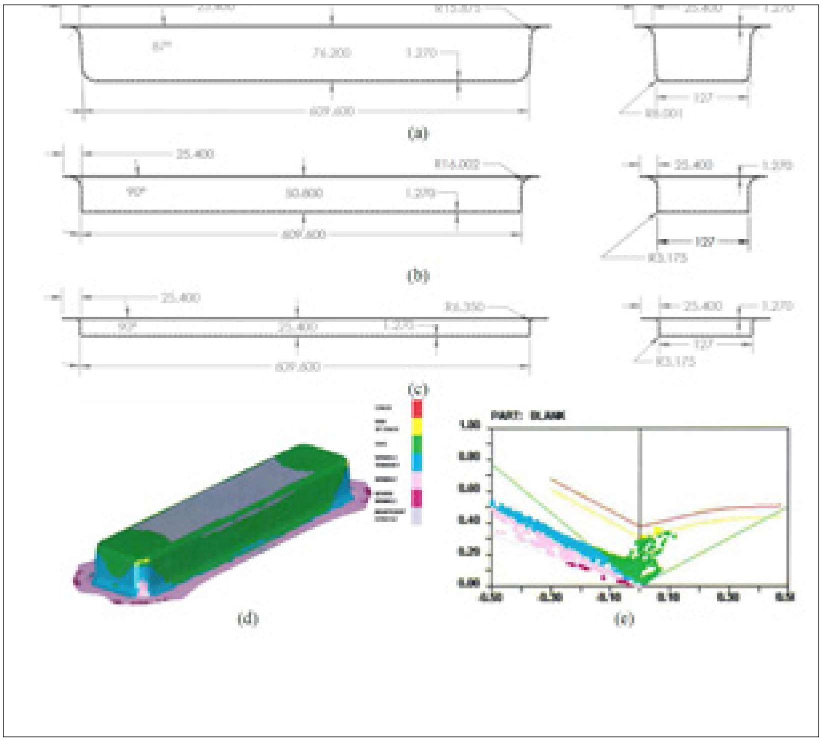


Fig 11 (a-c) Schematic representations of the designed dimensions of the HIP cans, versions 1-3 respectively, maximising depth while increasing design constraints, based on local strain and forming limit predictions. (d) Forming simulation for HIP can version 1 based on simulations of local strains and local material response from a forming limit diagram for DQ steel (e), which shows minor strain versus major strain allowing prediction of local variations in formability/failure/wrinkling as a function of strain state [3]

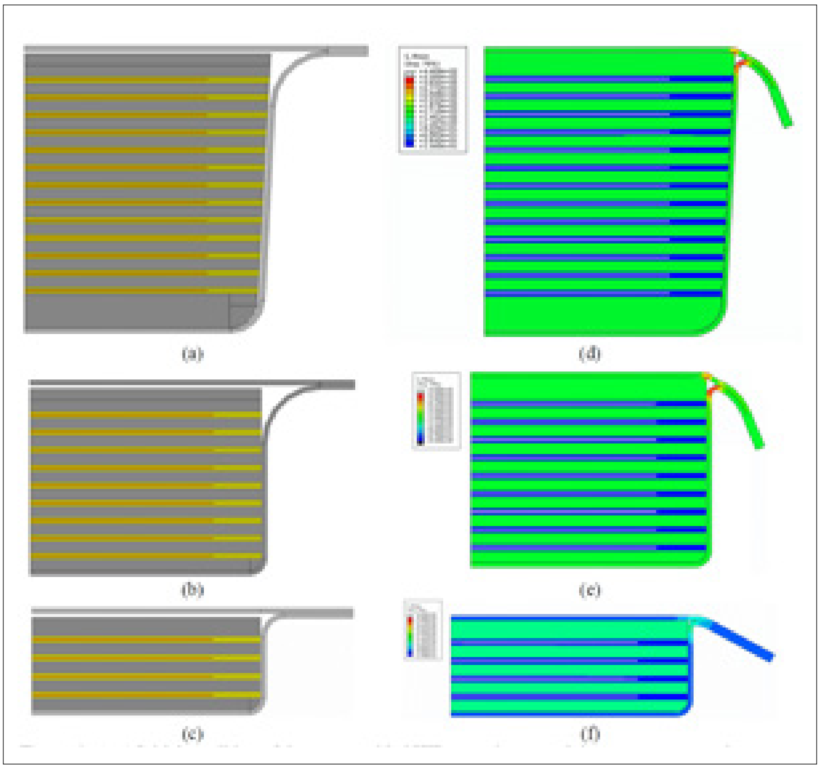


Fig 12 (a-c) Initial condition of the as-assembled HIP can prior to applying temperature and pressure in the FEA model, and (d-f) the Von Mises stress distribution through the HIP can for each version of the can [3]

fuel plates. In the developed process, the strong-backs can be recycled for re-use in a subsequent HIP run, but a new outer can is required for each set of fuel plates processed. The scaled-up baseline HIP can design involved substantial machining and over three metres of labour-intensive hand welding. Therefore, optimisation work is now ongoing to modify the baseline HIP processing path to enable high-volume manufacturing with improved efficiency. HIP can design goals have been set by LANL and Babcock & Wilcox (B&W) to minimise material usage, ease assembly and disassembly, eliminate machining and significantly reduce welding. Initial small-scale experiments and modelling have shown that a formed can approach can achieve these goals.

Efforts have then continued to scale-up this formed can approach. In the presented paper, results were shown detailing HIP can design considerations, modelling efforts and successful full-scale formed HIP can trials and providing further insights into optimising processing steps required to produce high-quality, repeatable fuel plates.

Based on the results with the small-scale formed cans, three full-size formed can designs were considered. Ideally, the formed can would have perfectly sharp punch and flange radii, vertical walls and could be formed to any desired depth. However, in practice, forming operations require compromises between these variables. Fig. 11 shows schematics of the three evaluated versions of the formed can, which were designed to maximise depth with the following assumptions: Version 1 (Fig. 11a) allows a 3° draft angle and large punch and flange radii, Version 2 (Fig. 11b) constrains to vertical walls and a smaller punch radius but allows a large flange radius and Version 3 (Fig. 11c) constrains to vertical walls and both smaller punch and flange radii. The dimensions shown represent the predicted maximum punch depth for each design, based on forming limit diagram analyses. The representative forming simulation and associated forming limit diagram for version 1 can design are given in Figs. 11d and 11e.

Fig. 12 presents FEA results of a two-dimensional half-transverse section, centred longitudinally, of each HIP can version, showing the as-assembled cans (Figs. 12a-c) and the Von Mises stress distribution on the internal plate stack at 560°C and 103.4 MPa during the HIP cycle (Figs. 12d-f). The Von Mises stress distributions indicate that versions 1 and 2 show higher maximum stress in the flange of the HIP can itself, giving a design that may be less robust in a production setting than version 3, which has a significantly tighter as-formed flange radius.

For experimental validation, each HIP can design was manufactured. For version 3, in addition to the low probability of failure as predicted by FEA, the vertical walls allow all strong-backs to be the same dimensions and interchangeable, easing re-use.

A number of important advantages of the formed cans, compared with the baseline design, were also noted:

- Total mass, including the lid but without the internal stack, was in the range 2.3 to 2.8 kg, compared with the baseline design, which uses 9.1 kg of material and has final mass of 6.4 kg
- The formed can is made from mild steel rather than stainless steel
- The reduced mass also improves manufacturability in terms of handling in processing
- Machining requirements are completely eliminated
- Total length of welding is reduced from 3 metres to 1.5 metres.

Experimental validation of the formed can was begun by processing a version 3 can with a stack of only stainless steel strong-backs and not including a parting agent. The images in Fig. 13 show the as-welded and as-HIPped can. In Fig. 13e, the individual layers of the internal stack are clearly visible through the can wall, suggesting that the can had collapsed fully onto the stack and that the HIP stresses were transferred effectively to the internal stack. The disassembly of the can required only the removal of the flange with a bandsaw, after which the internal stack was readily removed by turning the can over and lifting it from the stack.

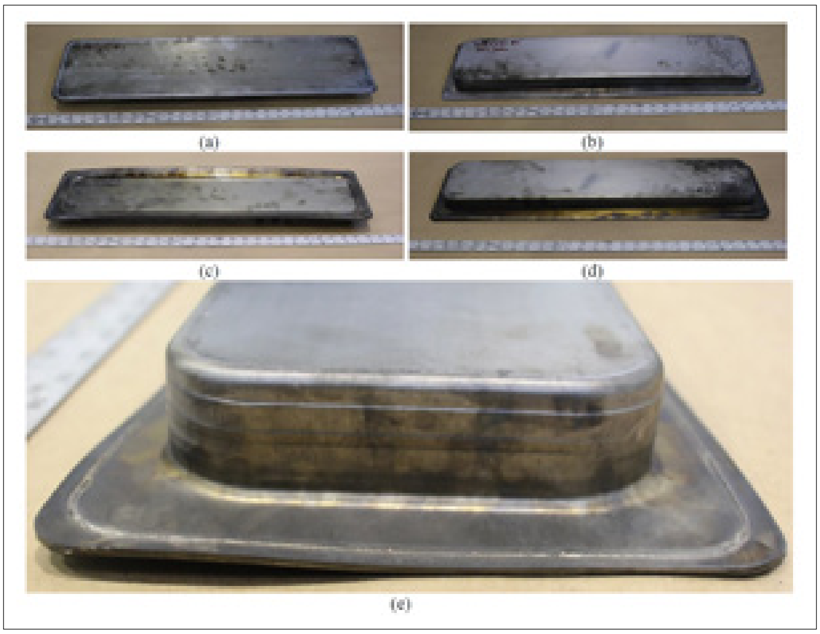


Fig 13 (a, b) Version 3 formed HIP can after electron-beam welding, ready for HIP processing. This can has only strongbacks in the internal stackup. (c-d) The can from (a, b) after HIP processing, showing excellent results: no bulging or breaches, and complete collapse of the can around the internal stackup. (e) After HIP, the individual layers of the internal stackup are visible through the HIP can walls [3]

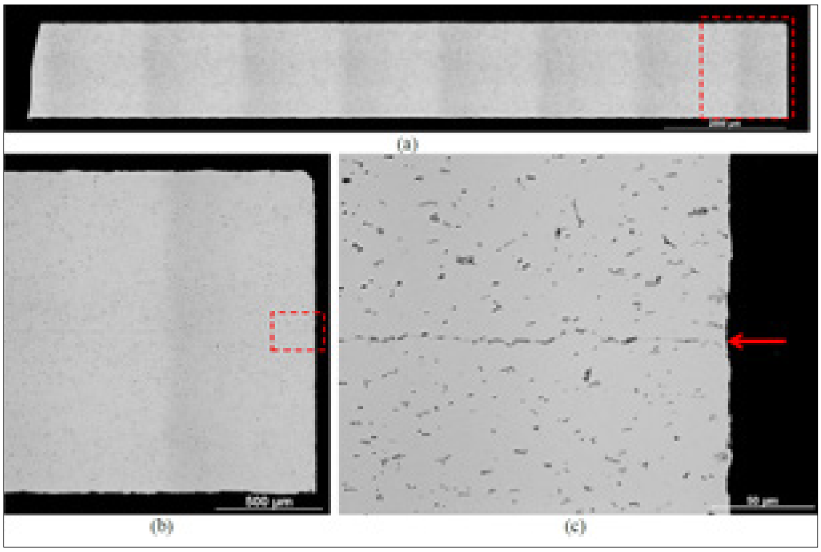


Fig 14 As-polished metallographic images of a representative aluminum-aluminum bonded plate from the version 1 HIP can shown in Fig. 8. (a) Full-thickness cross-section containing the edge of the plate (right side of image) and a sheared end (left side of image), (b) region highlighted with a red box in (a), and (c) region highlighted with a red box in (b). Arrow indicates the bond line [3]

The next stage of the evaluation involved the filling of a version 3 can with a stack that comprised aluminium-aluminium double layers between the strong-backs and a MoS_2 aerosol spray parting agent. After a vacuum furnace thermal

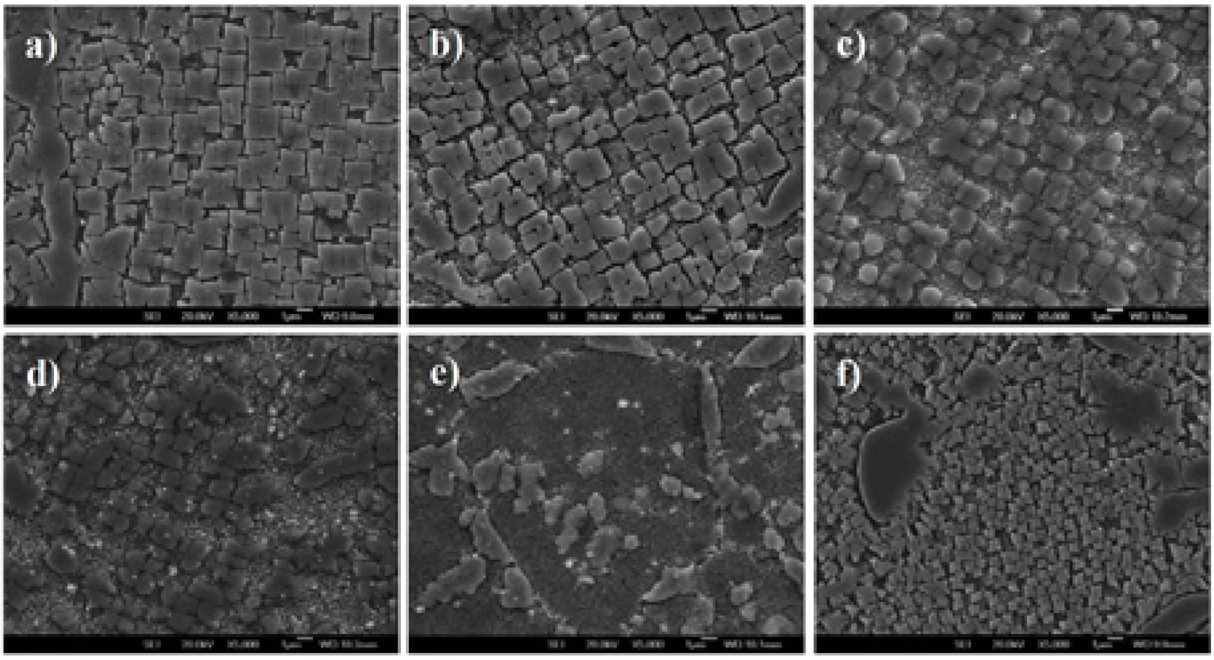


Fig 15 SEI-SEM (x5000). Effect of ST temperature on γ': As-HIP (a); Partial dissolution of γ_p' with gradual increase in channels of fine γ_s' particles between, with ST at 1125°C (b), 1150°C (c) and 1175°C (d); Majority of γ_p' dissolved leaving matrix of fine γ_s' particles, ST at 1200°C (e); Sufficient dissolution of γ_p' for γ_s' matrix to coarsen to a fine cuboidal morphology with ST at 1225°C (f) [4]

C	Al	Ti	Cr	Mo	Hf	Ta	Co	W	B	N	O	Ni
0.09	5.57	0.80	8.29	0.61	1.31	3.10	9.59	9.57	140ppm	<20ppm	<100ppm	Bal.

Table 3 Composition (wt.%) of CM247LC powder investigated [4]

cycle, substantial bulging of the can was observed, created by internal pressure arising from parting agent outgassing. Based on this result, further studies were conducted on a range of candidate parting agents (MoS2, BN and graphite) to determine mass loss versus temperature using thermo-gravimetric analysis (TGA) with simulated HIP thermal cycles.

These studies indicated that it is advisable to incorporate a bake-out step, using an evacuation tube, during the HIP process and that using a bake-out temperature of 400°C would provide a robust processing path independent of which parting agent were chosen.

Metallographic examination was carried out on aluminium-aluminium bonded plates processed in a version 1 can (Fig. 14). The aluminium-aluminium bond line is particularly evident in the higher magnification micrograph in Fig. 14c, which suggests that some inclusions are present at the bond line. Further examination via bond strength testing and/or electron back scattered diffraction are to be carried out to quantify the quality of the bond.

Overall, it has been concluded that each of the HIP can versions is viable, but that, to minimise the risk of can failure, to limit the assembled weight of each can and to allow for single-size strong-backs and aluminium plates, the version 3 can provides the most robust design. When combined with an evacuation tube bake-out at an appropriate temperature for the selected parting agent, the formed can approach addresses the initial goals set by LANL and B&W.

Heat treatment of Hot Isostatically Pressed nickel-based superalloy

Finally, a paper from J E MacDonald, M Aristizabal and M M Attallah of the University of Birmingham, UK, and M J Lunt, DSTL, UK, focussed on the influence of heat treatment on the microstructure and tensile properties of HIPped CM247LC nickel-based superalloy [4].

Certain microstructural issues with the HIPping of superalloys that can affect properties must be addressed before the net shape potential of HIP can benefit the production of high temperature aero-engine components, such as combustor or turbine casings. The detrimental effects of precipitation of a significant density of phases such as carbides, nitrides and oxy-carbo-nitrides at prior particle boundaries have been reported, as have brittle oxide phases that can occur due to inclusions from the atomisation process.

In previous work, HIP processing has been developed for CM247LC alloy powder to minimise such defects. CM247LC is a nickel superalloy with potential for operation at high temperature (>750°C), due to its high γ' (the

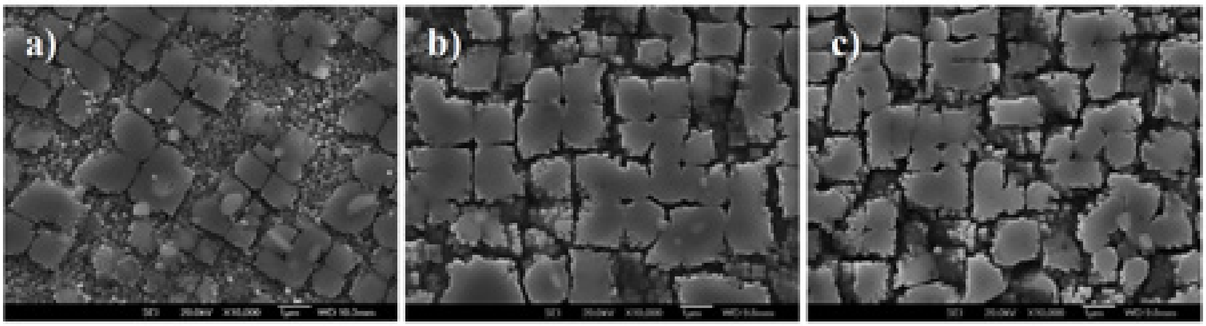


Fig 16 SEI-SEM (x10000). Effect of increased ST time: Coarsening of γp' via Ostwald ripening with increase in ST time at 1175°C for 1 hour (a); 2 hours (b); 4 hours (c) [4]

main strengthening phase in Ni-superalloys) volume fraction and also the fact that it has a moderate Cr level, which should help prevent the formation of brittle topologically close packed (TCP) phases during long holds at high temperature. However, published properties for HIPped CM247LC are limited. Furthermore, the influence of heat treatment on microstructure and mechanical properties of HIPped CM247LC is not fully understood.

In the reported investigation, therefore, the effects of post-HIP heat treatment on microstructure and mechanical properties of CM247LC have been studied, with the aim of achieving a balance between tensile strength, creep resistance and fatigue life. The re-opening of gas pores during heat treatment, known as thermally induced porosity (TIP), is one potential defect that must be considered when heat treating material HIPped with gas atomised powder. TIPs are often at or near triple points and high angle grain boundaries, which may be weakened by incipient melting. Such TIPs are potentially detrimental to properties, particularly fatigue life and crack growth resistance.

The material used in the investigation was an argon atomised CM247LC (LC = low carbon) powder, with the chemical composition shown in Table 3. When HIPped at the γ' solvus temperature, CM247LC exhibited a "necklace" structure, consisting of coarse γ' decorating the grain boundaries and fine γ' (~ 1 μm in size with irregular cuboidal morphology) distributed homogeneously throughout the grain interiors. The γ' volume fraction was found to be 62%.

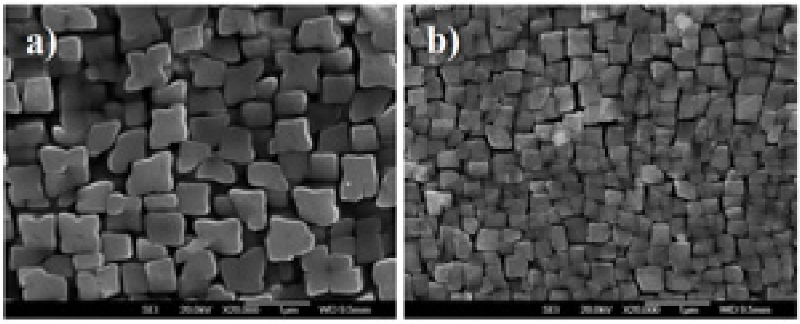


Fig 17 SEI-SEM (x20000). Effect of cooling rate from ST temperature: Air cooled sample, 1225°C/1.5h/AC (a); Gas fan quenched sample, 1225°C/1.5h/GFQ, surface cooling rate 4.16°C·s-1 (b) [4]

The necklace can contribute to irregular grain boundary morphologies, which can help inhibit grain boundary sliding, benefiting creep resistance. Other phases were identified in the microstructure: fine (Hf, Ta)C carbides and coarser hafnium oxides (HfO_2), these sometimes having alumina (Al_2O_3) cores thought to originate from the atomisation process. HIP at 1260°C generally promoted sufficient growth for grains to grow past prior particle boundaries, leaving carbides distributed within grains and at grain boundaries, eliminating continuous prior particle boundary networks from the microstructure.

The initial study of heat treatment response related to the effect of solution treatment temperature. Retaining some coarse γ' at grain boundaries can help to pin them and so sub-solvus solution treatments were trialled, in the γ' dissolution range but below the γ' solvus temperature, meaning that not all of the primary γ' (γ_p') was dissolved. Furthermore, since TIP increases with solution temperature and, as the solution temperature approaches the HIP temperature, solution treatment in the sub-solvus region helped to minimise TIP. Fig. 15 shows the microstructures obtained at various temperatures (1125°C, 1150°C, 1175°C, 1200°C and 1225°C, where the solvus temperature was 1260°C). As the solution temperature increased, the dissolution of γ_p' also increased. On cooling, it was re-precipitated as a finer secondary γ' (γ_s') phase.

Next, the influence of solution treatment time was assessed, by trialling each temperature for 1, 1.5, 2 and 4 hours. As can be seen from Fig. 16, the γ_p' appears to have slightly coarsened with longer times. At 1175°C, a significant fraction of γ_p' remained and it can be seen that, as solution time was increased, the channels between the γ_p' appeared narrower, the γ_p' particles had a more irregular morphology and some of

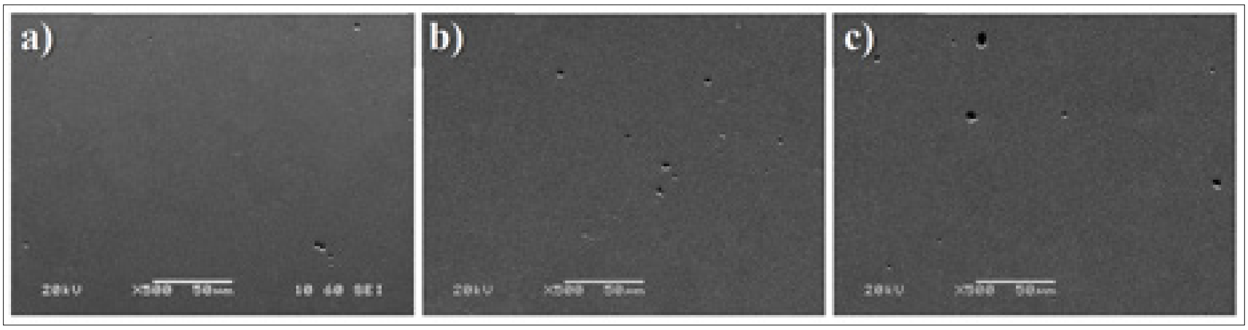
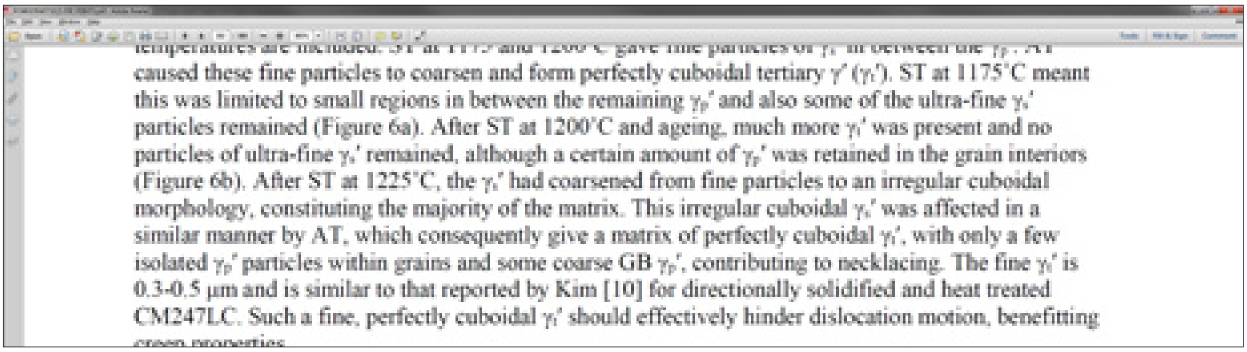


Fig 18 SEI SEM (x500). Increase in TIP with ST temperature: TIPs began opening around 1125°C and gradually increased in size and frequency with ST temperature at 1150°C (a), 1175°C (b) and 1225°C (c) [4]



caused these fine particles to coarsen and form perfectly cuboidal tertiary γ' (γ_t'). ST at 1175°C meant this was limited to small regions in between the remaining γ_p' and also some of the ultra-fine γ_s' particles remained (Figure 6a). After ST at 1200°C and ageing, much more γ_t' was present and no particles of ultra-fine γ_s' remained, although a certain amount of γ_p' was retained in the grain interiors (Figure 6b). After ST at 1225°C, the γ_s' had coarsened from fine particles to an irregular cuboidal morphology, constituting the majority of the matrix. This irregular cuboidal γ_s' was affected in a similar manner by AT, which consequently give a matrix of perfectly cuboidal γ_t', with only a few isolated γ_p' particles within grains and some coarse GB γ_p', contributing to necklacing. The fine γ_t' is 0.3-0.5 µm and is similar to that reported by Kim [10] for directionally solidified and heat treated CM247LC. Such a fine, perfectly cuboidal γ_t' should effectively hinder dislocation motion, benefitting

Fig 19 SEI-SEM (x10000). Effect of two-stage ageing treatment on fine γ': After ST@1175°C - fine γ_s' particles in between γ_p' has coarsened to form fine cuboidal γ_t', but γ_p' and some fine γ_s' particles remain (a); After ST@1200°C - mixed matrix with some γ_p' amongst perfectly cuboidal γt' (b); After ST@1225°C - matrix of perfectly cuboidal γ_t', with GB γ_p' retained and a few isolated γ_p' within grains (c) [4]

them appear to have joined together (Fig. 16 a-c). This was attributed to Ostwald ripening, whereby some of the fine γ_s' that has been dissolved can re-join the larger γ_p'.

The γ_p' volume fraction decreased as the solution temperature increased. However, for each temperature investigated, γ_p' was found to increase slightly with time, although this effect appeared to stabilise after two hours. Ostwald ripening may affect properties; for CM 247LC, the γ/γ' misfit strain is almost zero at room temperature and becomes negative at elevated temperatures. While misfit strains can impart strengthening, low misfit strains minimise Ostwald ripening, which enhances creep resistance.

The effect of cooling rate was assessed, by heat treating bulk samples under vacuum in a TAV furnace, equipped with argon fan quenching. The effect of the rapid quench can be seen in Fig. 17. The higher cooling rate of 4.16°C/sec from the gas fan quench served to "freeze" the γ_s', leaving it finer than when air cooling was used. The finer γ_s' should be more effective in hindering dislocation motion.

There is, however, another effect of cooling rate through the γ' solvus region, where a slower cooling rate can give significant grain boundary serrations. Grain boundary serrations have been found to improve significantly the stress-rupture properties of HIPped superalloy components. It may, therefore, be possible to optimise the cooling rate through the γ' solvus to give a balance of rapid quenching and development of grain boundary serrations. Significant development of grain boundary serrations has been reported as arising at a cooling rate around 1.0°C/sec.

Fig. 18 shows the development of TIP at the solution temperature was increased. TIPs began opening at as low a temperature of 1125°C and increased with temperature. TIP formation was also found to increase with solution time. The TIP volume fraction after solution treatment at 1225°C/4 Hours was 0.24%, considerably lower than the loose powder porosity value, Such TIPs are deemed as acceptable in terms of effect on properties since, when they are small, failure is more likely to occur from larger defects such as brittle non-metallic inclusions or the grain size itself. However, TIPs can potentially be detrimental to fatigue life and crack growth resistance, which may be a concern for aero-engine casing components under long holds at high temperature.

Subsequent to solution treatment, a two-stage ageing treatment (1079°C/4 hours/AC + 870°C/20 hours/AC) was applied to further refine the fine γ_s'. The effect of the ageing treatment on the γ' phase can be seen in Fig. 19. Solution treatment at 1175 and 1200°C gave fine particles of γ_s' between the γ_p'. The ageing treatment caused these fine particles to coarsen and form perfectly cuboidal tertiary γ' (γ_t'), . After solution treatment at 1225°C, the γ_s' had coarsened from fine particles to an irregular cuboidal morphology, constituting the majority of the matrix, This irregular cuboidal γ_s' was affected in a similar manner by the ageing treatment, which consequently gave a matrix of perfectly cuboidal γ_t' with only a few isolated γ_p' within grains and some coarse grain boundary γ_p' contributing to necklacing. The fine γ_t' is 0.3-0.5 µm and should effectively hinder dislocation motion, benefiting creep properties.

A full heat treatment of 1220°C/1.5 hours/GFQ+ 1079°C/4 hours/GFQ + 871°C/20 hours/GFQ was found to improve the tensile properties of the HIPped CM247LC materials. The improvement was attributed to the refined size and morphology of the γ' phase, serving to increase resistance to dislocation motion. The 750°C tensile properties are shown in Fig. 20. The yield strength (YS) increased from 780 to 888 MPa and the ultimate tensile strength (UTS) increased from 950 to 1060 MPa, while average ductility improved from 6.3% to 8.0%. The tensile properties were an improvement on those reported for cast CM247LC, whilst elongation was similar at around 8% (at 760°C). Values for UTS and elongation reported for directionally solidified CM247LC did, however, exceed the values for the HIP + HT material.

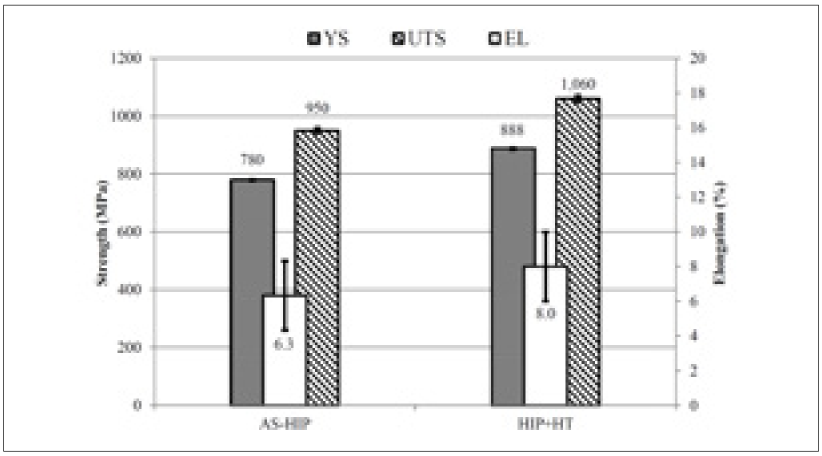


Fig 20 Elevated temperature (750°C) tensile test results of as-HIPped and HIP+HT CM247LC [4]

Author

Dr David Whittaker is a consultant to the Powder Metallurgy and associated industries.
Tel: +44 (0)1902 338498
Email: http://epsi-highpressure.com/

References

[1] Near Net Shape HIPed Beryllium and AlBe Blank Size and Shapes, A Morales, D Hashiguchi, Materion Beryllium & Composites, USA, as presented at POWDERMET2015, MPIF, USA

[2] Extruded discontinuously reinforced aluminum MMC's, D Hashiguchi, J Campbell, C Pokross, Materion Beryllium & Composites, USA, D Tricker, A Tarrant, Materion Aerospace Metal Composites, UK, as presented at POWDERMET2015, MPIF, USA

[3] Hot Isostatic Press Manufacturing of LEU-10 wt. pct. Molybdenum Monolithic Fuel Plates, K D Clarke, L A Tucker, S D Imhoff, M J Dvornak, B Aikin, V D Vargas, J D Montalvo, R Hudson, M E Mauro, and D E Dombrowski, Materials Technology: Metallurgy Group (MST-6), Los Alamos National Laboratory, USA, as presented at POWDERMET2015, MPIF, USA

[4] Influence of heat treatment on the microstructure and tensile properties of HIPped CM247LC, J E MacDonald, M Aristizabal, M M Attallah, University of Birmingham, UK and M J Lunt, DSTL, UK, as presented at POWDERMET2015, MPIF, USA

PM Industry Events

2015

Euromold 2015
September 20-25,
Dusseldorf, Germany
www.euromold2015.com

Euro PM2015
October 4-7,
Reims, France
www.epma.com

Ceramitec 2015
October 20-23,
Munich, Germany
www.ceramitec.de

APMA 2015 3rd International Conference on Powder Metallurgy in Asia
November 8-10
Kyoto, Japan
www.apma.asia

formnext
November 17-20,
Frankfurt, Germany
www.mesago.de/en/formnext

2016

PM16 International Conference
Febuary 18-20,
Pune, India
pmai.in/pm16

MIM2016 International Conference on Injection Moulding of Metals, Ceramics and Carbides
March 7-9, Irvine, USA
www.mpif.org

AMPM2016 Additive Manufacturing with Powder Metallurgy
June 5–7,
Boston, USA
www.mpif.org/Meetings/2016/AMPM2016

POWDERMET2016 International Conference on Powder Metallurgy & Particulate Materials
June 5–8,
Boston, USA
www.mpif.org

World PM2016 Congress & Exhibition
October 9-13,
Hamburg, Germany
www.epma.com/world-pm2016

Advertisers' Index