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SUMMER 2016

POWDER METALLURGY REVIEW

COMPANY VISIT: SHW

HIP AND HEAT TREATMENT

PM-16 CONFERENCE REVIEW

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

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POWDER METALLURGY REVIEW

Meeting the demands of greater fuel efficiency and lower emissions

Through lighter components and innovative design, Powder Metallurgy can contribute significantly to improving fuel efficiency and reducing harmful emissions from the internal combustion engine.

One company that is committed to providing solutions that contribute to the reduction of emissions is Germany's SHW Automotive GmbH. With its range of sintered products for engine and transmission applications SHW is a key supplier to the global automotive industry. The company's commitment to developing advanced Powder Metallurgy products that help manufacturers meet and exceed ever increasing environmental regulations is key to its success. We report on a visit to SHW's PM facility in Aalen-Wasseralfingen (page 37).

In this issue we also present how the combination of Hot Isostatic Pressing and heat treatment in a single, integrated, process can offer numerous advantages, helping reduce energy consumption and improve the delivery time for components that require both processes. Continued improvements in HIP equipment and a breakthrough in gas quenching at HIP pressures is providing a dramatic boost in what an integrated HIP and heat treat process can deliver. Dr Stephen J Mashl reports on the state of this game-changing development (page 45).

We also report on the recent PM-16 International Conference & Exhibition on Powder Metallurgy organised by the Powder Metallurgy Association of India in February. A number of interesting papers are highlighted from the diverse technical programme (page 57).

Paul Whittaker
Editor, *Powder Metallurgy Review*

Cover image
Powder Metallurgy camshaft adjustment part with densified surface (Courtesy SHW)

Summer 2016

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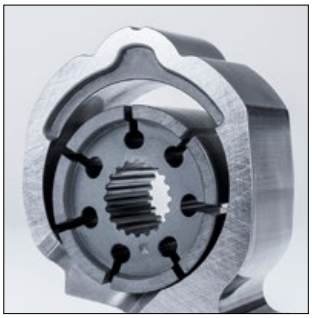
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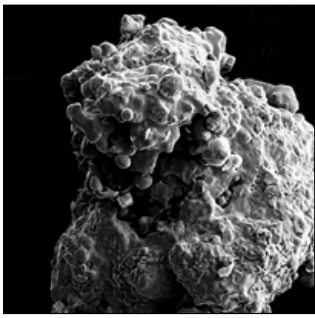
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industry news

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

Hoeganaes Corporation begins production of metal powder in China

Hoeganaes, part of GKN Powder Metallurgy, is starting production of high quality automotive grade powders in China for the Asian market. The new joint venture further expands GKN Powder Metallurgy's footprint in China and makes Hoeganaes the only atomised iron powder manufacturer with complete production facilities in the world's three major automotive producing regions.

The agreement with Chinese partner Bazhou Hongsheng Industrial Company Ltd sees GKN Powder Metallurgy taking a majority share in a manufacturing facility located in Bazhou City, Hebei Province, China.

The 24,600m^2 plant has been in operation since 2009 and will expand its product line to produce GKN Hoeganaes international grade powders for use in automotive and industrial applications in the growing Asian markets. These powders enhance the manufacturers' ability to achieve more complex geometries, improved dynamic properties and ultimately produce lighter weight components.

"For the first time this joint venture will provide a local manufacturing base for GKN's advanced metal powder technologies, enabling us to meet the increasing need for more technically enhanced powders in Asia," stated Peter Oberparleiter, CEO GKN Powder Metallurgy.

"It will allow us to better serve our customers in both China and the wider Asia Pacific area and is a reflection of our commitment to expanding our global footprint and meeting the needs of our customers."

Representatives of GKN Powder Metallurgy and Bazhou Hongsheng Industrial Company Ltd during the opening ceremony (Courtesy Hoeganaes Corporation)

Hoeganaes is one of the world's largest manufacturers of metal powder, the essential raw material for Powder Metallurgy, with manufacturing facilities in the United States, Europe and Asia.

www.hoeganaes.com

Ampal expands its aluminium powder production facility

Ampal, Inc., a wholly owned subsidiary of United States Metal Powders, Inc. (USMP), formerly United States Bronze Powders, Inc. (USBP), has announced the expansion of its aluminium powder production facility in Palmerton, Pennsylvania, along with the acquisition of an adjacent industrial property.

Ampal was founded in 1968 and its parent company, USBP, in 1918. Ampal moved its production facility from Flemington, New Jersey to its current location in 1982 and has been operating in Palmerton for the last 34 years. The company has grown to be the largest US producer of aluminium powder.

The newly purchased industrial property will facilitate the company's expansion by providing warehouse space and a new location for its Research and Development team which will be relocated from Flemington. The team has developed aluminium alloy powders for new and advanced technologies such as Metal Injection Moulding (MIM) and Additive Manufacturing (AM).

Once completed, the expansion is expected to create fifteen new jobs for a total employment at Ampal of over forty people. "After operating successfully for more than three decades in Palmerton, PA, this expansion provides an opportunity to create new job opportunities and to continue to drive our growth in the aluminium powder business. We are proud of our team of highly talented employees at Ampal today," stated K Clive Ramsey, President of Ampal and its parent company, USMP. "We look forward to continuing our strong ties to the local community and are pleased to be creating new employment opportunities."

www.ampal-inc.com

Plansee to expand production in South Korea

Plansee has announced it is expanding production capacity in South Korea following a groundbreaking ceremony for the construction of a new factory in Dongtan. The site is said to be close to a number of the company's important key customers and is due to start operation at the end of 2016.

Plansee stated that it is investing ten million euros in the project. The company plans to bring its existing production and sales sites in Korea under one roof at the new facility.

"Above all, it is our customers in the display and semiconductor industries that will benefit from the increased capacity. The construction of our own facilities underscores our long-term commitment to Korea," stated Bernhard Schretter, member of the Board of Directors at Plansee.

www.plansee.com

Metaldyne Performance Group reports profit up 6% during Q1

Metaldyne Performance Group Inc. has reported net sales of $739.5 million for the first quarter 2016, compared to $765.2 million in Q1 2015. Gross profit, however, was reported at $136.5 million for the quarter, an increase of 6% from Q1 2015.

Commenting on the company's results, George Thanopoulos, Chief Executive Officer of MPG, stated "We are extremely pleased with our first quarter results. Expansion of our margins and continued strong EBITDA despite certain macro headwinds show the strength in our business. Our solid cash flow gave us flexibility to increase our dividend, start our share repurchase program and build cash on the balance sheet. We are continuing to win new business and focus on fast growing powertrain applications. We are looking forward to a successful year in 2016."

Metaldyne Performance Group is a provider of highly-engineered components for use in powertrain and safety-critical platforms for the global light, commercial and industrial vehicle markets. The company's metal-forming manufacturing technologies and processes include aluminium die casting, forging, iron casting, Powder Metallurgy and Metal Injection Moulding as well as advanced machining and assembly.

Headquartered in Southfield, Michigan, Metaldyne Performance Group has a global footprint spanning 60 locations in 13 countries across North America, South America, Europe and Asia with approximately 12,000 employees.

www.mpgdriven.com

Kyocera acquires SGS Tool

Japan's Kyocera Corporation has announced that has acquired 100% ownership of US based SGS Tool Company. The company, located in Munroe Falls, Ohio, will be renamed Kyocera SGS Precision Tools, Inc.

Kyocera Corp. is the parent and global headquarters of the Kyocera Group and was founded in 1959 as a producer of fine ceramics. Since combining these engineered materials with metals and integrating them with other technologies, Kyocera has become a leading supplier of cutting tools, industrial ceramics, solar power generating systems, mobile phones, printers, copiers, electronic components and semiconductor packages. During the year ended March 31, 2015, the company's net sales totalled around $12.7 billion.

www.global.kyocera.com

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(*Elnik Systems will charge for 2 trial runs on DSH production equipment. Should a furnace be purchased within 1 year of these trial runs, Elnik will provide full credit for 2 trial runs off the price of the purchased equipment.)

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Metal Powder Products acquired by Millstein & Co

Metal Powder Products, headquartered in Westfield, Indiana, USA, has announced that it has been acquired by Millstein & Co., a diversified investment management and financial services firm. Metal Powder Products has three production facilities based in Pennsylvania and specialises in the production of Powder Metallurgy components, including custom-engineered gears and sprockets, complex structural parts, high strength aluminium parts and components for use in high stress, wear and magnetic applications.

The Millstein team has extensive experience owning and operating industrial companies and manufacturing businesses similar to Metal Powder Products. Metal Powder Products was formerly a subsidiary of Revere Industries, a leading manufacturer of high-performance metal and plastic components based in Indiana.

"Metal Powder Products' three factories in Pennsylvania produce excellent quality products that delight customers," stated Millstein & Co. Operating Partner Chuck Spears. "We are impressed with the teamwork and productivity of the workforce as they strive for excellence. We plan further investments in automation, material flow and capacity, working closely with our customers to meet and exceed their requirements."

Metal Powder Products experienced a record year in 2015 and is well positioned to capitalise on market trends. "We are impressed by Metal Powder Products' strong track record of innovation under the leadership of Ben James and his team of skilled professionals. The company's powder metal expertise has enabled it to deliver dynamic growth and we see great future potential driven by the company's market-leading aluminium capabilities. We look forward to working with Ben and his team to advance Metal Powder Products' business," stated Michael Duran, a Partner at Millstein & Co.

It was announced that existing Metal Powder Products executives have also made equity investments into the company, becoming minority shareholders. "The investment from Millstein & Co. strengthens Metal Powder Products' position for continued growth as a leading supplier of innovative, custom-engineered products in the powder metal industry," stated Ben James, President of Metal Powder Products. "My team is extremely excited for the opportunity to work with Millstein & Co. and I am confident that together we can successfully build on the scalable growth of our business."

www.metalpowder.com

New MPIF Standard 35 Materials Standard Released

The Metal Powder Industries Federation has announced that the 2016 edition of *MPIF Standard 35, Materials Standards for PM Structural Parts*, has been released. The Standard provides the design and materials engineer with the latest engineering property data and information available in order to specify materials for structural parts made using the PM process.

Revised and expanded, this new edition was developed by the Powder Metallurgy commercial parts manufacturing industry. Each section of the Standard is clearly distinguished by easy to read data tables and explanatory information for each material listed. Detailed notes and definitions, along with data cited in both Inch–Pound and SI units, help to make the standard more user friendly.

The updated publication does not apply to materials for PM self-lubricating bearings, Powder Forged (PF) or Metal Injection Moulded (MIM) products which are covered in separate editions of MPIF Standard 35. The next edition of MPIF Standard 35 Materials Standards for Metal Injection Molded Parts is due to be published shortly.

www.mpif.org

AMG boosted by sales of Powder Metallurgy induction furnaces

AMG Advanced Metallurgical Group N.V., headquartered in Amsterdam, The Netherlands, has reported a 4% increase in group earnings during the first quarter 2016. AMG stated that EBITDA (earnings before interest, taxes, depreciation and amortisation) totalled $21.2 million in Q1 2016, up from $20.4 million in Q1 2015. Net income attributable to shareholders increased to $12.0 million in the first quarter 2016 from $2.7 million in the Q1 2015.

AMG Engineering achieved EBITDA of $4.6 million during the first quarter 2016, a 49% increase from $3.1 million in Q1 2015. The Engineering division was reported to be continuing to experience strong demand in the areas of plasma re-melting furnaces for the aerospace market and induction furnaces for Powder Metallurgy applications.

AMG Critical Materials generated EBITDA of $16.5 million during the first quarter 2016, a 4% decrease compared to the first quarter of 2015. Year-over-year double-digit declines in average quarterly prices for all key products resulted in a 13% reduction in revenues in the first quarter 2016 compared to the first quarter 2015, the company stated.

"AMG earnings for the first quarter were strong despite continued year-over-year weakness in metal prices. AMG did experience a modest improvement in select metal prices compared to the fourth quarter 2015. AMG's focus on operational excellence and price risk management has resulted in solid financial results under difficult market conditions," stated Dr Heinz Schimmelbusch, Chairman of the Management Board and CEO.

www.amg-nv.com

Summerev Hard Materials meeting to take place at Hilti

The EPMA's European Hard Materials Group will be holding its Summerev 16 meeting at Hilti AG, Liechtenstein, June 16-17, 2016.

Summerev 16 will focus on the characterisation of interfaces and associated chemistry and phase metrology of substrates and adjacent matrices, with additional presentations on the influence of these parameters on elevated temperature properties. It is intended that interfaces can be interpreted at both the microscopic scale (interphase) and mesoscopic (coatings, substrates, etc) and elevated does not just mean very high temperatures but also intermediate, around 600-800°C.

www.epma.com

Sandvik reorganises business areas and identifies non-strategic operations

Sandvik has announced plans to reorganise and consolidate its operations in the Sandvik Venture business area. The new structure, effective July 1, 2016, will see the Sandvik Venture business area and management team dissolved, with Jim Nixon, current President of Sandvik Venture, leaving the company.

The restructuring will include moving Wolfram (Wolfram Bergbau und Hütten) and two selected production sites from Sandvik Hyperion into the Sandvik Machining Solutions business area. These businesses are internal suppliers to Sandvik Machining Solutions. The selected production sites in Sandvik Hyperion supply metal powder and develop round tool blanks.

Sandvik Drilling and Completions (Varel) will move into the Sandvik Mining and Rock Technology business area. The product offering comprises consumables such as drill bits and down-the-hole products for the oil and gas and mining industries.

Sandvik announced that Sandvik Process Systems and Sandvik Hyperion, excluding the two sites to be merged into Sandvik Machining Solutions, have been identified as non-strategic operations and will remain in Sandvik Venture, now to be labelled 'other operations'. The company announced that it plans to exit from these businesses, although the process is yet to be initiated.

"By consolidating operations we will achieve total ownership and accountability for the respective businesses, aiming to improve the long term efficiency in Sandvik," stated Björn Rosengren, Sandvik's President and CEO.

"For Sandvik Machining Solutions the structural change is driven by achieving total ownership of the supply chain and strengthening the position in the round tools segment. For Sandvik Mining and Rock Technology we consolidate the similar product offering of Rock Tools and Drilling and Completions under the same umbrella. Over time we will exit from the businesses now reported in other operations, making Sandvik even more focused on its core businesses," added Rosengren.

www.sandvik.com

Kennametal announces fiscal 2016 third quarter results

Kennametal Inc. has reported mixed results for the 2016 fiscal third quarter ended March 31, 2016. Sales were $498 million, compared with $639 million in the same quarter last year. Sales decreased by 22%, reflecting a 10% decline due to divestiture, an 8% organic decline and a 4% unfavourable currency exchange impact.

Operating income was $27 million, compared with an operating loss of $120 million in the same quarter last year. Adjusted operating income was $39 million, compared with $56 million a year ago. Kennametal stated that the decrease in adjusted operating results was driven primarily by organic sales decline, unfavourable mix, lower fixed cost absorption and unfavourable currency exchange, offset partially by lower raw material costs and restructuring benefits. Adjusted operating margin was 7.8% in the current period and 8.8% in the prior year period.

"Kennametal's third quarter performance reflects progress from operating results in a challenging environment, and benefited from a favourable tax rate," said Ron De Feo, Kennametal President and CEO. "Infrastructure made progress, posting adjusted operating income of $10 million compared with losses for the first half of the year, and Industrial results reflect better sequential margins as well with adjusted operating income of $30 million. Adjusted EPS, while still lower year-over-year, strengthened sequentially as a result of the higher gross margins and lower operating expenses."

"We have a lot of improvement opportunities within Kennametal to simplify operations, lower costs and drive margin improvements over time. We need to be more customer responsive and grow market share with innovation, entrepreneurship and speed - all things we are working on and plan to discuss with the investment community in the future," De Feo continued.

www.kennametal.com

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www.powdermetalpresses.com

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Miba announces record capital expenditure of over €110 million

Miba AG has reported that consolidated revenue climbed by 7% to €719.1 million in its last fiscal year (February 1, 2015, to January 31, 2016). Investments in property, plant and equipment reached a new all-time high of almost €80 million and those in research and development a record €31.8 million. The number of employees also continued to rise. As of January 31, 2016, Miba had 5,397 members of staff working at 22 sites worldwide.

The past fiscal year showed Miba's main fields to be running at two different speeds. While the automotive industry performed strongly, as it had done in the previous year, Miba faced weak to downward trends in segments of the capital goods market. "The past fiscal year has proven once again how important our diversified business model is, especially in volatile times, and that flexibility and continuous development are the watchwords," said CEO F. Peter Mitterbauer.

Global demand for construction machinery, mining equipment and ships fell again in 2015. The truck market turned in a satisfactory performance in the US and Europe, but in China declined sharply, particularly from the second half of the year onwards. The markets for tractors and locomotive applications were on a stable trend, while demand for power electronics components for energy transmission showed a slightly positive trend.

Miba is an important partner to all renowned manufacturers in the above market segments with its development and production of engine bearings, sintered components, friction materials, coatings, power electronics components and special machinery.

Consolidated revenue climbed by EUR 49.8 million year on year to EUR 719.1 million. Earnings before interest and tax (EBIT) amounted to EUR 82.9 million (2014/2015: EUR 81.9 million). "The earnings performance reflects the challenging market environment," Mitterbauer explained.

Miba stated that it intends to grow organically and through acquisitions. "In addition to expanding our established lines of business, we also intend to broaden our product portfolio through acquisitions. With our expertise in technologically sophisticated components, we are also able to create added value in other areas around the megatrends mobility and energy efficiency," Mitterbauer added.

"The dynamic environment we are operating in at present and rapid technological progress demand an even sharper focus on innovation and technology. Only in this way can we offset any sustained market weakness through an appropriate increase in new product launches and thus continue to extend our technology and product leadership," Mitterbauer concluded.

www.miba.com

Call for Papers issued for the 19th Plansee Seminar 2017

A Call for Papers has been issued by organisers of the 19th Plansee Seminar, the International Conference on Refractory Metals and Hard Materials, taking place at the headquarters of the Plansee Group in Reutte, Austria, from May 29 – June 2, 2017.

Authors are invited to submit abstracts for papers to be presented in either lecture or poster format. All papers must contain unpublished results that are of current interest and abstracts should clearly outline the aim of the work and the methods employed, as well as the major results and conclusions. The deadline for submission of abstracts is September 9, 2016.

The presentations at the Plansee Seminar will include all areas where products based on Refractory Metals and Hard Materials play an important role, or where they are promising alternatives to present material solutions.

www.plansee-seminar.com

New vibratory sieve shakers aim to make sieve analysis more convenient

Retsch GmbH, Haan, Germany, has announced a new generation of its vibratory sieve shakers. The new sieve shakers are claimed to offer easy and convenient operation, ensuring accurate, reliable and user-friendly grain size analysis. The Retsch AS 200 and AS 300 vibratory sieve shakers also include optimised control and vibration decoupling, resulting in the machines running very quietly.

Improvements to the model range include the updating of the entry-level model, AS 200 basic, to include digital control, a standard feature on other models in the AS 200 series. Parameters such as performance and time are now visible on the display.

The AS 200 digit cA model now operates with controlled amplitude which is indicated in the display, just like the sieving time. The high-end

model AS 200 control has been further optimised and can now be equipped with up to ten sieves. New features include the storage of up to 99 sieving programs as well as USB connection for use of EasySieve® evaluation software. The AS 300 control for sieves with a 300 mm diameter is now also available in the new design.

www.retsch.com

Höganäs adds 17-4 stainless steel to its AM range

Sweden's Höganäs AB has extended the range of materials suited to its Digital Metal® Additive Manufacturing technology by including high performance 17-4 PH stainless steel. According to Höganäs, 17-4 PH enables production of components with high strength and hardness.

The material is a hardening grade exhibiting considerably higher strength compared to the more commonly used austenitic 316L. It also provides improved corrosion resistance compared to 400 series ferritic stainless steels.

Digital Metal is a 3D metal printing technology enabling production of small and complex objects that would be costly, if not impossible, to produce using traditional methods.

www.hoganas.com

Carpenter Technology reports third quarter results

Carpenter Technology Corporation has announced financial results for the quarter ended March 31, 2016, in which the company reported a net loss of $23.9 million. Net sales for the third quarter of fiscal year 2016 were $456.3 million. Net sales excluding surcharge were $402.4 million, a decrease of $60.5 million (or 13%) from the same quarter last year, on 11% lower volume.

The operating loss was $24.3 million, a decrease of $29.1 million from the third quarter of the prior year. The operating loss included $54.7 million in primarily non-cash impairment charges related to certain assets in the company's oil and gas businesses within the Performance Engineered Products (PEP) segment as well as other special items.

Operating income, excluding pension earnings, interest and deferrals (EID) and special items, was $35.2 million, compared to $35.1 million in the prior year period. These results primarily reflect lower volume, offset by an improved product mix and lower operating costs compared to the same period one year ago, the company stated.

During the quarter, the company experienced growth as expected across the Aerospace & Defence, Medical and Industrial & Consumer end-use markets on a sequential basis. The Energy end-use market was also higher driven by strong performance in the Power Generation sub-segment, while the Oil and Gas sub-segment was down significantly on a sequential basis.

"Despite challenging conditions, we continue to believe the Energy end-use market is strategically important given our strong customer relationships and the value our material solutions bring to demanding applications that require high strength and corrosion resistant products," stated Tony Thene, Carpenter's President and Chief Executive Officer.

Free cash flow in the third quarter of fiscal year 2016 was $47 million, compared to $87 million in the same quarter last year. Capital expenditures in the third quarter of fiscal year 2016 were $16.6 million, compared to $24.8 million in the prior year's third quarter.

For the full year, Carpenter continues to expect inventory to decline in the fourth quarter and finish largely in-line with year-end fiscal 2015 levels. The Company now expects capital expenditures to be approximately $85 million to $95 million for fiscal year 2016, versus prior guidance of $100 million.

www.cartech.com

Federal-Mogul reports increased sales in first quarter 2016

Federal-Mogul Holdings Corporation has announced financial results for the first quarter ended March 31, 2016, stating that net sales for the first quarter were $1,897 million, compared to $1,835 million in Q1 2015, a $62 million or 3% increase.

Aftermarket sales growth in the US and Canada as well as sales from the acquired valvetrain business, were partially offset by $52 million of negative impact from currency exchange rate fluctuations. Gross profit was $288 million, or 15.2% of sales, a 1.5 percentage point margin improvement, compared with Q1 2015.

The improved gross profit margin was driven primarily by higher aftermarket sales in the US and Canada, operational improvements in both divisions as well as the favourable impact of ongoing restructuring and integration programs. Net income from continuing operations attributable to Federal-Mogul in the quarter was $35 million, compared with a net loss from continuing operations attributable to Federal-Mogul of $11 million in Q1 2015. Adjusted net income in Q1 2016 was $52 million and operational EBITDA in Q1 2016 was $193 million, compared to $142 million in Q1 2015.

Federal-Mogul's Powertrain division reported first quarter revenue of $1,128 million, compared to $1,138 million in the same prior year period. The slight decrease in Powertrain's revenue was principally driven by a $30 million negative impact from currency exchange rate fluctuations and a $13 million decrease in inter-segment sales, partially offset by revenue from the acquired valvetrain business.

Federal-Mogul's Motorparts division reported first quarter revenue of $831 million, compared to $773 million in the prior year period. Revenue growth of $80 million was partially offset by a $22 million negative impact from currency exchange rate fluctuations.

www.federalmogul.com

HC Starck joins Worcester Polytechnic Institute's Center for Heat Treating Excellence

HC Starck has announced it is to partner with the Worcester Polytechnic Institute (WPI) Center for Heat Treating Excellence (CHTE), based in Worcester, Massachusetts, USA. The CHTE is an alliance between the industrial sector and university researchers that addresses short and long-term needs in the heat treating and thermal processing industry.

"We are very excited to join the team at WPI Center for Heat Treating Excellence," stated Dmitry Shashkov, Member of HC Starck's Executive Board and Head of the Fabricated Products Division. "With our commitment to quality and technological expertise, we work side-by-side with our customers to ensure they have the highest quality product. We are also rapidly growing our business to match the demands of the global marketplace, working with OEM and aftermarket furnace manufacturers on their new designs. To match this growth, HC Starck has made significant investments in our fabrication capabilities and we are leading the development of new materials for high temperature applications to improve cost and performance for our customers."

HC Starck's product portfolio includes boats, trays, heating elements, thermal shields, hot zones, furnace racks and assemblies. The company added that its team of research engineers are continually developing new materials for high temperature vacuum and inert atmosphere furnaces for industrial processes such as annealing, brazing, heat treating, HIP, melting, pre-heating, powder processing, sintering, tempering and MIM.

These innovative materials help improve furnace cycle time, maintain temperature uniformity and reduce carbon contamination. The benefits for customers include less component rejections, better handling and reduced production cost compared to graphite and ceramics.

www.hcstarck.com
www.wpi.edu

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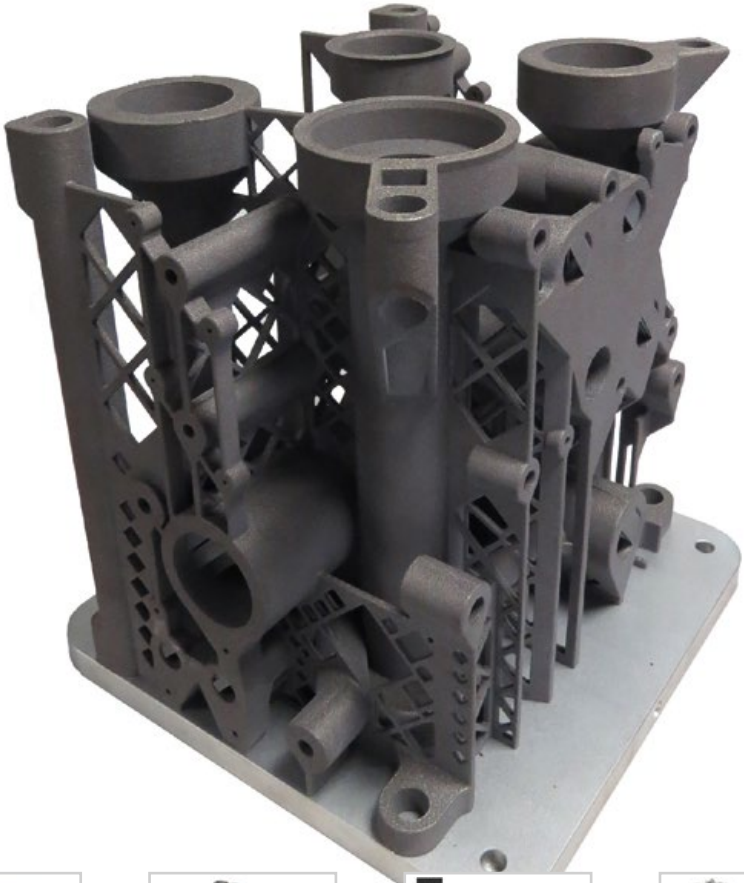

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Ultrafine gas atomised powders available from Atomising Systems

Atomising Systems Limited, Sheffield, UK, has announced that significant research and development work has been undertaken on its gas atomiser systems to address the increasing market for ultrafine gas atomised powders. Following work to improve the tundish system, the 200 kg batch capacity gas atomiser has now been upgraded with a high power gas heater allowing much higher atomising gas temperatures to be achieved.

Coupled with extensive work on ASL's gas atomising nozzle system, the upgrades enables the production of stainless steels with a median particle size of less than 20 microns. Further investment in uprated sieving and classification systems also allows ASL to undertake powder separations from over 100 microns down to less than 5 microns. With these upgrades ASL states that it has more than doubled its production capacity for the finest grades.

It was announced that the company's quality control laboratory has also received a significant boost with a new Malvern Mastersizer, a total oxygen determination instrument, a compaction press and tensometer for green determination of water atomised powders and an XRF chemical analyser. All are now in operation, assuring the quality and consistency of the ultrafine gas atomised powders.

"While a massive increase in orders for water atomised powders has kept us very busy, we have not neglected to develop our capability to serve our gas atomised powder clients with new grades for Metal Injection Moulding, Additive Manufacturing, Hot Isostatic Pressing and thermal spray processes amongst others. These investments are already proving to be extremely beneficial," stated Simon Dunkley, ASL's Managing Director.

Gas atomising at Atomising Systems Limited

"This QC laboratory investment of well over £200,000, coupled with the recruitment of extra laboratory staff, ensures ASL can provide a QC service exceeding that expected of our demanding clients."

www.atomising.co.uk

Bodycote becomes first company in Europe to pass MedAccred audit

Bodycote has announced that its facility in Derby, UK, has received MedAccred accreditation. MedAccred, administered by Performance Review Institute, is an industry managed approach to ensuring critical manufacturing process quality throughout the medical device supply chain. Bodycote Derby is the first facility in Europe to earn the MedAccred accreditation.

Bodycote Derby offers heat treatment and Hot Isostatic Pressing (HIP) services to the medical device and implants markets in Europe. MedAccred establishes stringent consensus audit criteria based on industry and specific OEM requirements that ensure compliance and quality.

Joe Pinto, Executive Vice President and Chief Operating Officer of the Performance Review Institute, the organisation which administers the MedAccred program on behalf of the medical device industry, sent his congratulations to the team at the Bodycote Derby facility. "We are delighted that Bodycote has the honour of becoming the first company to receive an accreditation from MedAccred in Europe. To be the first in anything demonstrates a high level of foresight and commitment to a long term strategy. The MedAccred audit is challenging and, in achieving accredited status, Bodycote's Derby facility has proven it has the capability to meet and exceed the requirements of its medical customers. The entire team should be proud of their success."

www.bodycote.com

Sinterite renews ISO/IEC 17025:2005

Sinterite, a Gasbarre Furnace Group Company located in St. Marys, Pennsylvania, has announced the renewal of its ISO/IEC 17025:2005 accreditation, allowing the furnace maker to continue to perform certified calibrations for furnace users. The ISO 17025 Accreditation is similar to the 9001 Standard, held by several other Gasbarre companies, but is more specific in requirements for competence. It applies directly to organisations that produce testing and calibration results and is the primary ISO Standard used by testing and calibration laboratories.

Similar to the other standards, ISO 17025 allows accredited companies to carry out procedures in their own way, but an auditor may ask the company to justify its methods.

www.sinterite.com

Hideshi Miura and Cesar Molins named as 2016 APMI fellows

Professor Hideshi Miura, Kyushu University, Fukuoka, Japan, and Dr Cesar Molins, Director General, AMES S.A., Barcelona, Spain, have been named as 2016 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.

Professor Hideshi Miura is considered one of the leading Japanese academics in PM. He is widely recognised by significant awards including the Japan Institute of Metals Distinguished Achievement Award and has contributed to over 300 publications. As a member of APMI for over 25 years, Miura currently serves on the APMI International Liaison Committee. He is a past President of the Japan Society of Powder and Powder Metallurgy and was co-chair of the 2012 PM World Congress in Yokohama.

Miura serves on several editorial boards and has headed significant developments in ferrous press and sinter technology, including fatigue analysis, Metal Injection Moulding and the evolution of heterogeneous high strength microstructures, and recently developed laser based AM for titanium and super alloys.

Dr Cesar Molins has actively promoted the PM industry for more than three decades. His deep understanding of the technology and of how to best utilise the advantages of PM versus other manufacturing technologies, has contributed substantially to market growth for PM manufacturers globally. Molins has supported PM as an active member of the European Powder Metallurgy Association (EPMA) for over 20 years, with two terms as President. During his presidency he was instrumental in promoting cooperation between EPMA, MPIF, and JPMA.

Professor Hideshi Miura (left) and Dr Cesar Molins (right)

Molins has been a member of APMI for over 30 years and serves on the APMI International Liaison Committee. He oversees several PM manufacturing facilities in Spain, Eastern Europe and North America.

www.mpif.org

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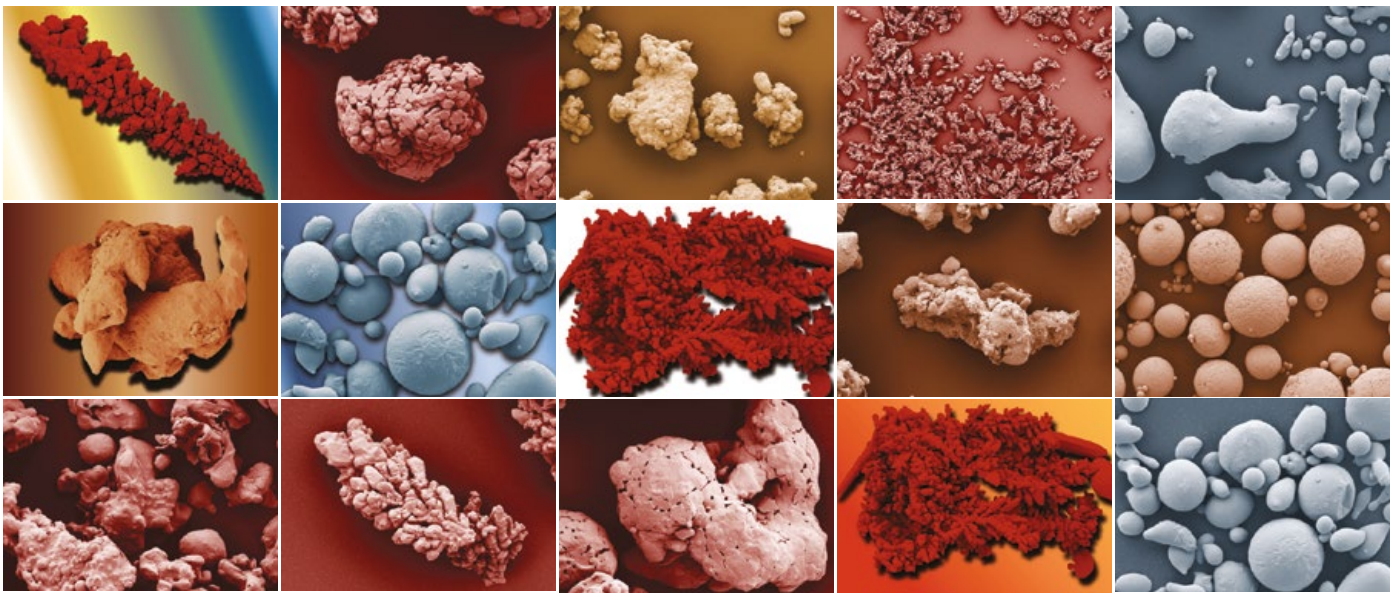

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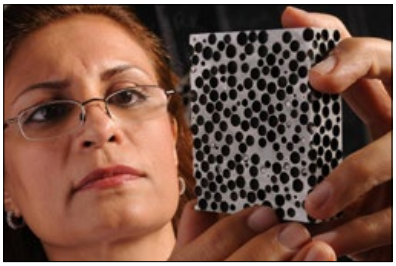
Composite metal foam can stop bullets and shield from radiation



The Advanced Materials Research Lab (AMRL) at North Carolina State University, USA, is reported to be developing a new class of metallic foam that combines the benefits of metal matrix composites with metallic foams. The composite metal foam (CMF) could have numerous applications and has recently been shown to stop armour-piercing bullets, as well as being able to shield radiation and offer extremely good thermal insulation.

The research has focused on developing the technology to process composite metal foams through both PM and casting techniques. The CMF has up to eight times higher energy absorption compared to any other metal foam made from similar materials and its energy absorption is almost two orders of magnitude higher under loading compared to the original bulk materials.

Afsaneh Rabiei, Professor of Mechanical and Aerospace Engineering at NC State, has worked on developing CMFs and investigating their unusual properties. With support from the US Department of Energy's Office of Nuclear Energy, Rabiei and her team showed that CMFs are very effective at shielding X-rays, gamma rays and neutron radiation.

Other potential applications of CMFs is in blast and ballistic armour. The results of Rabiei's experiments have shown that CMFs were able to absorb the major portion of the total kinetic energy of projectiles effectively, in addition to stopping both types of type III and type IV (armour piercing) projectiles. Further studies on the capability of CMFs to protect against larger threats and blast are still ongoing.

"We could stop the bullet at a total thickness of less than an inch, while the indentation on the back was less than 8 millimetres," stated Rabiei. "To put that in context, the NIJ [National Institute of Justice] standard allows up to 44 mm indentation in the back of an armour."

The researchers have also subjected the material to high speed impact testing for automotive and train applications. These tests showed very high energy-absorption capabilities at a variety of impact speeds from quasi-static up to 100 metres per second. This indicates the potential for utilising CMFs in crash energy management systems in trains, cars and buses.

www.ncsu.edu

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Getrag's joint venture transmission plant now operational in Wuhan

A joint venture between Germany's Getrag and Chinese partner Dongfeng Motor Corp has resulted in the construction of a new transmission plant in Wuhan. The site is now operational and is expected to produce 250,000 six-speed dual clutch transmission systems annually.

The partners have invested €120 million (US $136.1 million) in the plant, according to a statement from Dongfeng, a state-owned automaker headquartered in the central China city of Wuhan. Production capacity will reach 500,000 units by 2019 and one million units eventually. As well as supplying Dongfeng, the transmission plant will supply other automakers in China, including Dongfeng Peugeot Citroen and Shanghai General Motors, stated Xiong Aiguo, General Manager of the joint venture.

Getrag is one of the world's largest transmission makers and has a plant in Nanchang in east China's Jiangxi province which supplies Jiangling Motor Group Co., a state-owned producer of light commercial vehicles. Getrag signed the joint venture agreement with Dongfeng in October 2012.

Dongfeng makes cars and trucks under its own brand. It also has passenger car joint ventures with Honda, Nissan, Kia and PSA Peugeot Citroen.

www.getrag.com | www.dfmc.com.cn

Researchers seek to extract rare earth minerals from coal

Researchers at Virginia Tech, Blacksburg, USA, are working with academic and industry partners in a $1 million pilot project to recover rare earth elements from coal and coal by-products. Funded in part by a US Department of Energy National Energy Technology Laboratory grant, Virginia Tech engineers will test hydrophobic-hydrophilic separation (HHS) technology, a patented process that takes advantage of properties of water-friendly and water-repellent materials to extract rare earth elements from coal waste.

"The majority of rare earths is produced in China as by-products," stated Roe-Hoan Yoon, Director of the Center for Advanced Separation Technologies at Virginia Tech. "With the recent closure of the rare earth mine in California, the US relies more heavily on imports. It will be good for the country if we can develop an advanced separation technology to extract the critical materials from coal as by-products, particularly the high-value rare earths essential for advanced manufacturing industries."

If the currently funded Phase I project is successful, researchers will seek $6 million in Phase II funding that will involve construction and testing of a mobile facility to be tested at different coal cleaning facilities in the central Appalachian coal field.

www.vt.edu

GKN Sinter Metals receives supplier award from Maxon Motor

GKN Sinter Metals S.p.a. AG in Bruneck, Italy, has announced it has received a 2015 Supplier Award for "Best Overall Performance" from Maxon Motor. The award, given to suppliers who excel in quality and delivery reliability, was presented in the "Tool-Specific Components" category.

Maxon Motor is the world's leading supplier of high-precision drive systems. The family-owned company was founded in 1961 and employs a staff of more than 2,000 worldwide. GKN Sinter Metals in Bruneck supplies the Maxon Motor locations in Sachseln, Switzerland and Sexau, Germany, mainly with bearings for electric motors as well as planetary gears and carriers for industrial actuators.

"We're all very proud and honoured to receive this prestigious award. It really proves that we are doing things right. We will continue this path and strive to push the limits for highest product quality, perfect customer service and the most innovative products in the market," stated Marco Bernadi, GKN Account Manager for Maxon Motors.

www.gknsintermetals.com

Höganäs looks to improve environmental impact of transporting metal powders

Sweden's Höganäs AB has announced that it is testing a new high-capacity transport (HCT) truck for carrying metal powder from the manufacturing site in Höganäs to the port of Helsingborg. Working in cooperation with Volvo and GDL Transport, Höganäs claim that loading two containers instead of one will lower carbon dioxide emission by up to 35%.

Each year Höganäs AB dispatches 200 000 tonnes of metal powder from Höganäs to Helsingborg port for further transportation to Asia and North and South America. The aim of the HCT project is to reduce the number of vehicles from eight to four vehicles per day. "This is an important part of our sustainability efforts. In the future we will be able to halve the number of transports between the cities," stated Melker Jernberg, CEO of Höganäs AB.

The project is using the new Volvo FH16, a fuel efficient truck design that also has the ability to disengage and raise the drive axle when unladen, further lowering fuel consumption.

www.hoganas.com

Altus Capital Partners II, L.P. Acquires Nichols Portland from Parker Hannifin

Altus Capital Partners, an investment firm focused on middle market manufacturing companies in the USA, has announced the acquisition of Nichols Portland, a division of Parker Hannifin Corporation. Nichols Portland is a leading manufacturer of precision Powder Metallurgy fixed and variable displacement gears including gerotor gears and smart pumps for automotive and on-off highway and other industrial markets. Altus Capital along with the management team at Nichols Portland are reported to have made this investment in order to participate in the expected growth of smart pump and advanced variable vane gears.

Nichols Portland was founded in 1904 as WH Nichols and has its manufacturing operations headquarters in Portland, Maine, USA. The company's business comprises Powder Metallurgy and steel components for fixed and variable displacement pumps and the smart pump business comprises mechanical and electronically driven fuel and oil pumps.

Altus and the management of Nichols Portland believe that demand for smart pump and advanced variable vane gears will increase based upon these products ability to offer increased fuel and motor efficiency. "We are very excited to be partnering with Altus Capital Partners as we continue to grow. Nichols Portland has consistently built on its foundation of innovation and engineering excellence and we look forward to the resources that Altus Capital can provide to help us achieve our strategic growth objectives," stated Rick Izor, Nichols Portland's General Manager.

Nichols Portland is a leading manufacturer of PM gerotors

Russell Greenberg, Managing Partner of Altus Capital, added, "Altus is enthusiastic to partner with Nichols Portland's management team in acquiring an industry leader in the designing and manufacturing powder metal gerotor gears and a growing developer of innovative smart pumps for fuel applications."

www.gerotor.net

GKN Sinter Metals to showcase expertise in PM and AM at Engine Expo 2016

GKN Sinter Metals has announced that it will showcase key Powder Metallurgy developments in engine component design at this year's Engine Expo in Stuttgart, Germany, May 31 to June 2. The company will also give insight into its Additive Manufacturing capability and the technology's untapped potential with a lecture at the open technology forum during the event.

GKN Sinter Metals states that it offers a broad range of experience for developing AM processes and technologies and, as a full service provider, the company is offering a one-stop solution for its customers. This includes in-house material development of water atomised and gas atomised powders, offering tailored powder solutions to match customers' needs for consistency and purity.

The company added that it is able to support component design by using FEA based topology optimisation. By using bionic honeycomb or mesh structures, combined with topology optimisation based on differentiated material loads, the optimal load flows within a minimum amount of material can be defined. Based on a series of long-term material analyses and a strong simulation competence, GKN is enabled to optimise the structure of the components.

In-house materials test centres offer services for tensile testing, service life tests, elevated temperature testing or tribological testing.

The lecture, Additive Manufacturing – from Rapid Prototyping to Serial Manufacturing, will be presented by Simon Höges, Manager Additive Manufacturing at GKN Sinter Metals, during the forum on May 31 at 14:40. GKN Sinter Metals will exhibit on stand 3304.

www.gknsintermetals.com

Jandeska to be recognised for lifetime achievements in Powder Metallurgy

William F Jandeska, Jr, President, Midwest Metallurgical, Ltd., Rockford, Illinois, USA, has been selected to receive the Kempton H Roll PM Lifetime Achievement Award by the Metal Powder Industries Federation (MPIF). The award will be presented at POWDERMET2016 in Boston, Massachusetts, June 5-7, 2016.

Jandeska has distinguished himself as an expert in the field of Powder Metallurgy through developing innovative components and relationships between suppliers and vendors. He has promoted the continued growth of PM for more than 44 years through the joint involvement of part fabricators and the end-user community, which is evident by his support and leadership activity in MPIF, APMI, SAE and ASM.

Beginning his career as an intern at US Steel and Caterpillar Tractor, Jandeska worked whilst completing his BS, MS, and PhD from the University of Illinois. After completing his degrees in 1971, Jandeska joined General Motors Research Labs for a 20-year tenure, which included an appointment to assist the DoD National Technology Leader for GM with responsibility for high-performance magnetics, Powder Forged connecting rods, main bearing caps and development of advanced gearing materials. In 1991, he joined GM Global Powertrain Group as manager for PM technology and lead subject matter expert for the PM creativity team, positions he held until his retirement in 2006.

Jandeska has received numerous awards, including the MPIF Distinguished Service to Powder Metallurgy Award and the MPIF Automotive Achievement Award. He also

co-chaired both the 1989 Powder Metallurgy Conference & Exhibition and the 2002 World Congress on Powder Metallurgy and Particulate Materials, in addition to chairing the MPIF Technical Board from 1989 to 2003. Jandeska has conducted APMI International chapter presentations on technology, needs and the direction of the automotive industry; authored numerous technical papers and presentations at MPIF/APMI annual conferences; and has held numerous seminars educating hundreds of GM personnel worldwide. Jandeska is an APMI International Fellow, ASM International Fellow and received the SAE McFarland Award and the ASM Outstanding Young Member Award.

www.mpif.org

ABSTRACT SUBMISSION DEADLINE: SEPTEMBER 30, 2016

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Soft magnetic iron powder cores used in performance hybrid electric motors

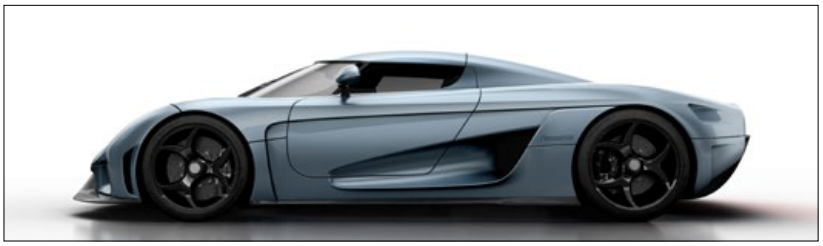
Iron powder producer Höganäs AB of Höganäs, Sweden, reports that its Somaloy soft magnetic composite powder is being used to produce the stator core components for three high performance electric motors in the hybrid drive system of the Koenigsegg Regera.

The Regera hybrid was developed by Koenigsegg of Sweden as a luxury Megacar alternative to Koenigsegg's traditional extreme, light weight, race-like road cars and is capable of accelerating from 0 to 400 km/hr in less than 20 seconds. The car features a 5.0 litre V8 internal combustion engine combined with three extremely compact axial flux electric motors from YASA Motors Ltd in Oxford, UK. Together, the ICE and electric motors provide 1500 Hp (1.1 MW) of power via a direct drive transmission that excludes a traditional gearbox. Each axial flux high performance electric motor contains a number of pressed Somaloy 5P stator cores produced by SG Technologies, Rainham, UK.

Christian von Koenigsegg, CEO of Koenigsegg stated "The three electric motors in the Regera constitute the most powerful electric motor set-up in production car history, replacing the gears of a normal transmission while adding power, torque, torque vectoring and yet still able to remove weight. YASA's motors are extremely power dense, making them the key-ingredient for the direct drive system."

There are two direct drive YASA-750 motors in the Regera delivering 1600 Nm/360 kW on the rear axle for traction and a single engine speed YASA-400 motor generator unit delivering 350 Nm/160 kW of electrical power, torque gap filling and starter motor functionality. "The torque capability of the YASA motors has given the Regera an acceleration capability that is second to none," added Koenigsegg.

www.hoganas.com



The Koenigsegg Regera incorporates the most powerful electrical motor set-up in production car history

Brazil's Senafor event to include PM conference

The organisers of Brazil's 36th Senafor, October 5 – 7, 2016, Porto Alegre, have announced that this year's event will include the 12th National Meeting of Powder Metallurgy and 6th International Conference Powder Metallurgy – Brazil.

Also forming part of the 36th Senafor will be the 20th International Conference of Forging – Brazil; the 19th National Conference of Metal Sheet Forming / 6th International Conference of Metal Sheet Forming / 3rd Congress of BrDDRG as well as the 6th International Conference on Materials and Processes for Renewable Energy.

The conference will include lectures, keynote presentations and specially invited speakers. Those interested in presenting their research either orally or as a poster should do so before May 31, 2016.

www.senafor.com

Results of EFFIPRO Project to be presented at World PM2016 workshop

The results of the three year EFFIPRO project, to develop a significantly shorter Powder Metallurgy process using a new concept of hybrid electrical current assisted sintering, are to be discussed during a dedicated workshop on October 9, 2016. The Energy Efficient Process of Engineering Materials (EFFIPRO) Project, part funded by the EU (FP7) and industry partners, was launched in September 2013, with the objective of using the novel sintering method to process hard materials with improved properties, thus resulting in a more energy efficient and cost effective process.

The project intended to focus on two different technologies, Electrical Discharge Compaction (EDC) and Electrical Resistance Sintering (ERS), with the initial goal of producing pilot plant scale equipment.

Members of the EFFIPRO consortium

It was planned that high performance metallic composites (based on hardmetals, WC-Co) and engineering metallic materials be processed using this technology to shorten the processing time and produce materials with enhanced properties (hardness, toughness and lifetime). It was predicted that the use of this process would bring significant energy consumption reduction in the sintering process.

The EFFIPRO Workshop will take place on Sunday October 9 during the World PM2016 Congress and Exhibition, Hamburg, Germany.

www.effipro.org

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SHW Automotive: A global supplier of gear pump and camshaft phaser components

Few industrial enterprises can look back on 650 years of uninterrupted operation such as SHW. Today, with its Powder Metallurgy plant in Aalen-Wasseralfingen, SHW Automotive GmbH is a specialist manufacturer of sintered parts for engines and transmissions and is recognised as a leading supplier of automotive pumps. Dr Georg Schlieper recently visited SHW's Powder Metallurgy facility and reports on the company's activities for *Powder Metallurgy Review.*

With a history dating back more than 650 years, SHW AG is one of the longest established companies in the metalworking industry. Over the centuries the company has re-invented itself many times and today is recognised as a technological leader in the production of vehicle components contributing to a reduction in CO_2 emissions. At its headquarters in Aalen-Wasseralfingen, Southern Germany, the management are proud that, thanks to the diligence, inventive spirit and a strong business acumen at SHW, the company has managed to adapt to the many changing market conditions over the years.

The acronym SHW stands for Schwäbische Hüttenwerke, translated as Swabian Ironworks, and the earliest documented evidence of the company dates back to 1365 when mining and smelting of iron ore was the main business activity. For centuries, the area in the Swabian Jura was the German centre of iron mining and the metalworking industry before the Ruhr Region emerged and took leadership in the Industrial Revolution. Iron ore was mined in the surrounding hills and charcoal was burned in the woods. When the iron ore deposits ran dry and mining was no longer attractive, SHW turned to casting technology and machine building in the 19th century. Rails and wheels for the expanding railway network and bearings for railway bridges were among the key products of SHW at that time.

The company's inventive spirit was again demonstrated in 1925 when SHW designed an automobile that

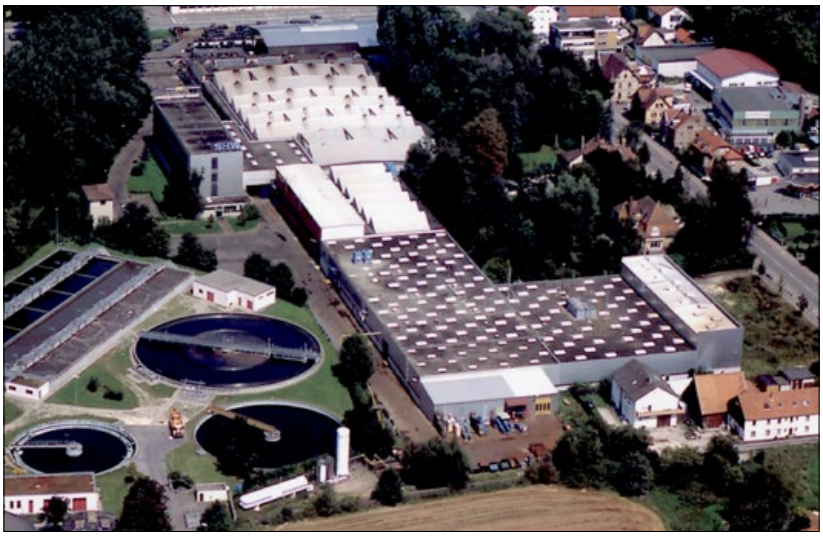

Fig. 1 Aerial view of SHW Automotive GmbH in Aalen-Wasseralfingen (Courtesy SHW)

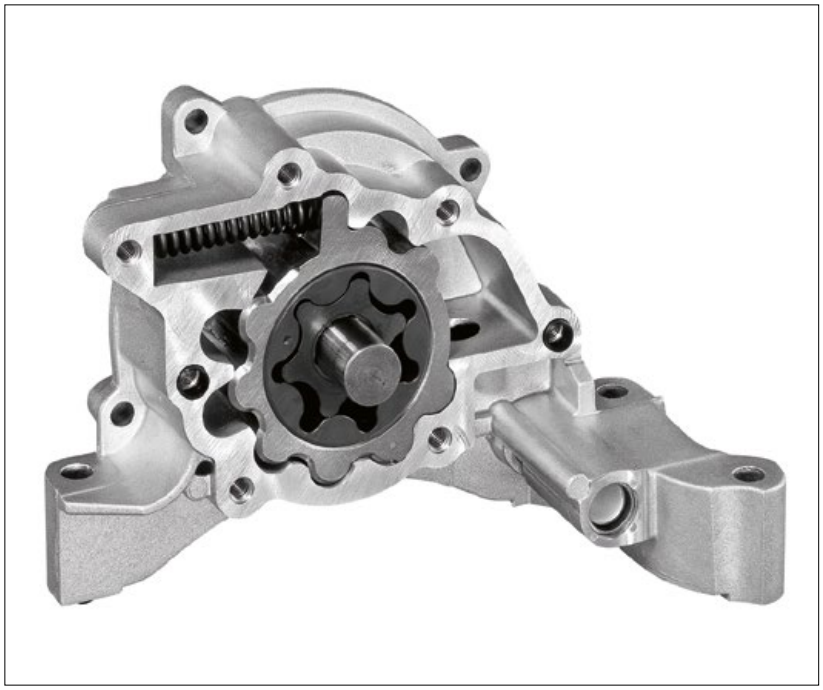

Fig. 2 The development and production of variable oil pumps is one of the main focuses of the SHW Group (Courtesy SHW)

was for that time highly advanced, with an aluminium body and independent suspension. It expressed the high technical competence of the company, but unfortunately was never produced in series. The prototype is still exhibited in the German Museum of Technology in Munich.

The first sintered components were produced at SHW in 1962. From the beginning, gear pump components were among the main products manufactured and this product family grew quickly during the 1970s. In 1978 the decision was taken to assemble pump components and manufacture the entire pump in order to increase added value. This led to a general specialisation in components of the engine periphery.

A major turning point in the history of SHW came in 2005. Prior to that date, the former Schwäbische Hüttenwerke was half owned by the MAN Group, one of Europe's leading commercial vehicle and mechanical engineering groups, and half owned by the state of Baden-Württemberg. In that year both shareholders decided to end their engagement in SHW GmbH and the entire automotive activities were transferred into Schwäbische Hüttenwerke Automotive GmbH, which is also the legal successor and holder of the rights associated with name and logo of SHW. Its holding company, named SHW AG, went public in July 2011.

"...gear pump components were among the main products manufactured and this product family grew quickly during the 1970s"

Other business units, such as machine tool building, machining technology, casting technology, storage and handling solutions and forging technology became independent enterprises. All descendants of the old SHW GmbH continue to use the SHW logo with permission of SHW Automotive.

Facts and figures

SHW AG has two business segments, firstly Pumps and Engine Components and secondly Brake Discs. In the Pumps and Engine Components division, SHW develops and produces engine and transmission components, including variable engine oil pumps (Fig. 2), electrical auxiliary pumps for start-stop systems and oil and vacuum pumps. Its product range also includes pumps for industrial applications. Powder Metallurgy components for use in these systems are manufactured at the SHW plant in Aalen-Wasseralfingen and the components are assembled at the plant in Bad Schussenried. In the Brake Disc business segment SHW develops monobloc ventilated cast iron brakes as well as light weight composite brake discs. The company manufactures brake disc blanks at its foundry, most of which it then finishes itself at the Neuhausen ob Eck plant.

In 2015 SHW generated group sales of €463 million. Pumps and Engine Components contributed 79% of the total business and 21% came from the Brake Disc business. SHW has four production sites in Germany, as well as facilities in Canada, China and Brazil. The group has a total staff of around 1287 employees.

Currently SHW is creating a global production network and expanding in to markets in North and South America as well as Asia. Facilities have been established in Toronto, Canada, São Paulo, Brazil and Kunshan, China. It is expected that these sites will soon provide a significant contribution to SHW's sales growth. "SHW thinks and operates as a global player," stated Jörg Herrmann, Plant Manager Powder Metallurgy at SHW Automotive in Aalen.

The Pumps and Engine Components business segment is divided into three business units: Powder Metallurgy, Passenger Cars and Industry. The Powder Metallurgy business unit produces around 30 million PM parts per year from a production floor space of 16,000 m².

The plant operates in three daily shifts and in 2015 a value of €57 million was generated by approximately 330 employees. Roughly half of the production is delivered internally to the SHW pump assembly plant in Bad Schussenried and the other half is sold externally to OEMs and Tier 1 suppliers in the automotive industry.

"Substantial investments of around €20 million have been made in the Powder Metallurgy plant during the last three years to increase production capacity to cover increasing business," stated Herrmann. Further investments are planned with the objective of improving the production efficiency.

Fig. 3 Powder press in operation (Courtesy SHW)

Technical facilities

SHW Automotive GmbH has installed the entire process chain for producing powder metal parts including a tool shop, a variety of powder and sizing presses ranging from mechanical presses to hydraulic presses with 40 to 800 tons capacity (Fig. 3). The conveyor belt sintering furnaces operate at 1120°C, with synthetic gas mixtures or endogas as protective atmosphere. Sinter hardening is available as well as normal cooling. A number of furnaces are integrated with powder presses in automatic manufacturing lines (Fig. 4).

All powder presses are equipped with balances and the weight of all green parts is automatically controlled. Feedback is given to the press and the fill height is automatically corrected as soon as the programmed limit values are exceeded. The closed-loop press control ensures maximum part-to-part consistency.

Finish machining operations, for example turning and grinding operations, are an important part of the manufacturing process. The tight tolerances on the part height of most pump parts are met by double disc grinding (Fig. 5). SHW keeps height tolerances for highly efficient engine components that meet the customer requirements. Cylindrical

Fig. 4 Powder press in an automated manufacturing line (Courtesy SHW)

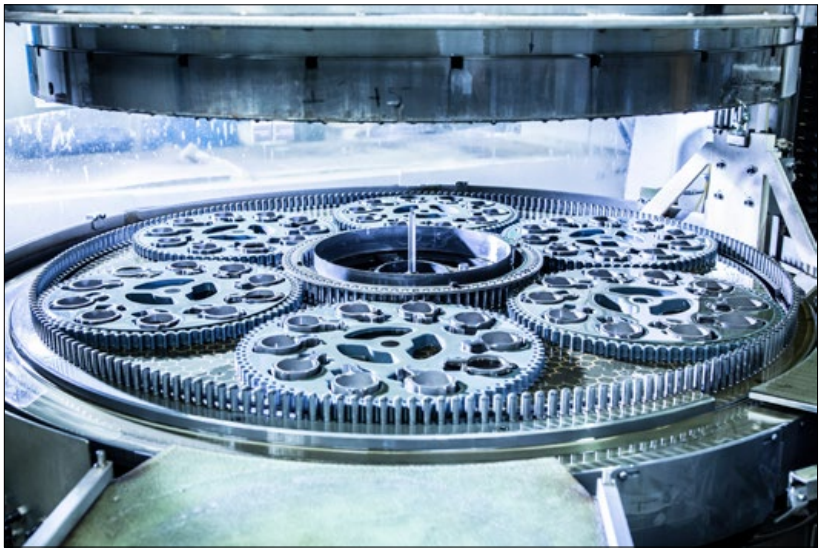

Fig. 5 Disc grinding of top and bottom faces (Courtesy SHW)

grinding on outer diameters can also be offered if required.

A continuous steam treatment furnace is installed in-house. However, other surface treatments such as nitriding, case hardening or electroplating are supplied by external providers.

Quality management

SHW has a certified quality and environmental management system as required for suppliers of the automotive industry. "Statistical process control procedures are installed in every processing step so that irregular parameters are immediately detected and corrective action can be taken," stated Herrmann. A strong focus is given to advanced preventive quality management.

Besides the most common quality inspection tests, such as dimensional and weight control, a materials lab regularly monitors the material quality. Magnetic particle inspection is used for crack detection and advanced non-destructive test methods such as eddy current and acoustic tests are installed.

"Our quality management system is based on continuous improvement in all processing steps. It is an important factor in our business strategy that contributes to the reduction of manufacturing costs," added Herrmann.

"Our quality management system is based on continuous improvement in all processing steps. It is an important factor in our business strategy"

Key competencies

Precision is one of the key success factors following the tighter regulatory CO_2 requirements. Hydraulic parts for pumps and camshaft phasers require extremely close tolerances to guarantee reduced leakage especially for the upcoming fuel-efficient engine oils. In this regard SHW has developed key competencies in processing and sophisticated production equipment for the cost efficient mass production of pump and camshaft phaser components.

One of the key competencies of SHW is a special technology that combines deburring and sizing in one production step. This is both a technical and economic advantage because it avoids a separate deburring step, such as barrel finishing, that might negatively affect the dimensional accuracy of the products.

Machining is also an important part of SHW's technology. The machining of green parts with cost effective drilling and milling operations is a well established part of SHW's technology portfolio. "The overall manufacturing costs of various products are lower when intelligent use is made of green state machining," stated Jörg Herrmann.

Surface densification of sprockets and camshaft gears is achieved in a special sizing cold forming process that improves the tooth shape and at the same time increases the strength. Mechanical components such as camshaft phaser parts achieve properties close to wrought steel while still maintaining the shape capabilities of the Powder Metallurgy process (Fig. 6).

SHW is one of the few PM companies worldwide manufacturing sintered aluminium products. The benefits to the customer of using high-strength and wear resistant sintered aluminium components for engines include saving weight and lowering inertia, achieving higher dynamics and helping to improve fuel efficiency.

Fig. 6 Camshaft adjustment part with densified surface (Courtesy SHW)

A wide range of products that improve efficiency and reduce CO_2

SHW produces PM parts mainly for the automotive sector. Most applications are closely related to engines and transmissions, with roughly half of all production used in pumps. Among the remaining products, camshaft phaser parts are predominant. Individual parts for use in the car body and seat adjustment units are perhaps the only exceptions.

A major focus for SHW Automotive is to reduce the harmful

emissions of internal combustion engines. Mechanical engine and transmission components can contribute to this ambitious task as well as innovative fuel-saving oil pump designs. SHW is determined to actively influence automotive technologies by continuous innovation of high quality PM products at competitive prices.

Metal components that move relative to each other need lubrication, usually by oil. SHW's oil pumps generate the required pressure where it is needed with a minimum of energy consumption. The company holds numerous patents in this field and has played a leading role in the development of pump concepts containing high precision PM components.

In contrast to other pump manufacturers who purchase PM components from external suppliers, SHW combines the competence of the pump system and sintered core components of a pump. This tight integration results in an optimal customer benefit regarding efficiency, packaging and, last but not least, cost.

The most important product family consists of gear pumps and variable vane pumps. Modern cars contain up to four oil pumps, one for the engine, a primary and secondary oil pump for the transmission and a servo pump for power steering.

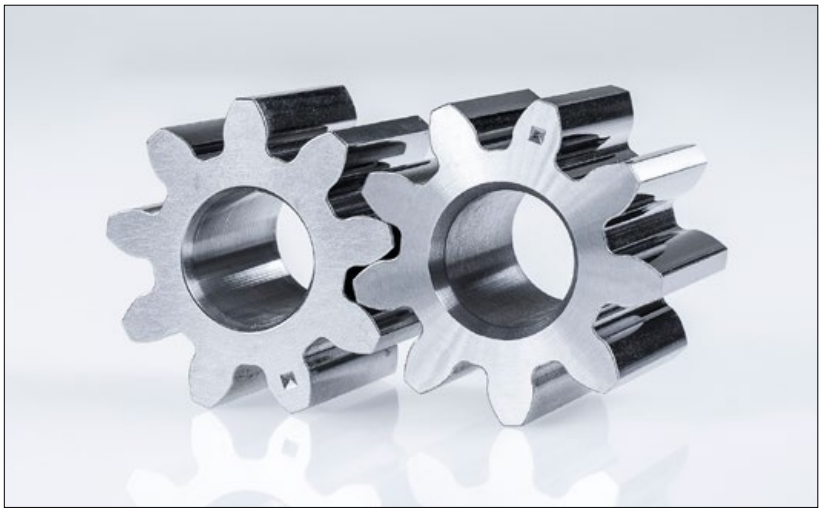

Fig. 7 Two spur gears for an external gear pump (Courtesy SHW)

External gear pumps

External gear pumps contain two spur gears (Fig. 7), one of which is driven by an external power source and drives the other gear. These gears usually include involute teeth. Oil is sucked in the radial direction on one side and pushed out radially on the other side. The pump volume is determined by the gear diameter, module and height. The quantity of oil pumped can be varied by shifting the two gears against each other in the axial direction, then the pump volume is reduced and oil is pumped only by a part of the gear length. A variation of the rotational speed of the gears also affects the output, of course. External gear pumps are suited for medium rotational speed and high output.

Internal gear pumps

Internal gear pumps consist of a gear with internal toothing that eccentrically embraces a spur gear. Two examples of internal gear pumps are shown in Fig. 8. Various tooth shapes are used, for example g-rotor or duocentric. Usually the inner rotor is the driving gear. Oil is sucked in from the side in the axial direction and also pushed out in the axial direction.

Unlike external gear pumps, the output of internal gear pumps cannot be varied by changing the pump volume. SHW developed a variable internal gear pump, which enables the angle of eccentricity to change in relation to the housing.

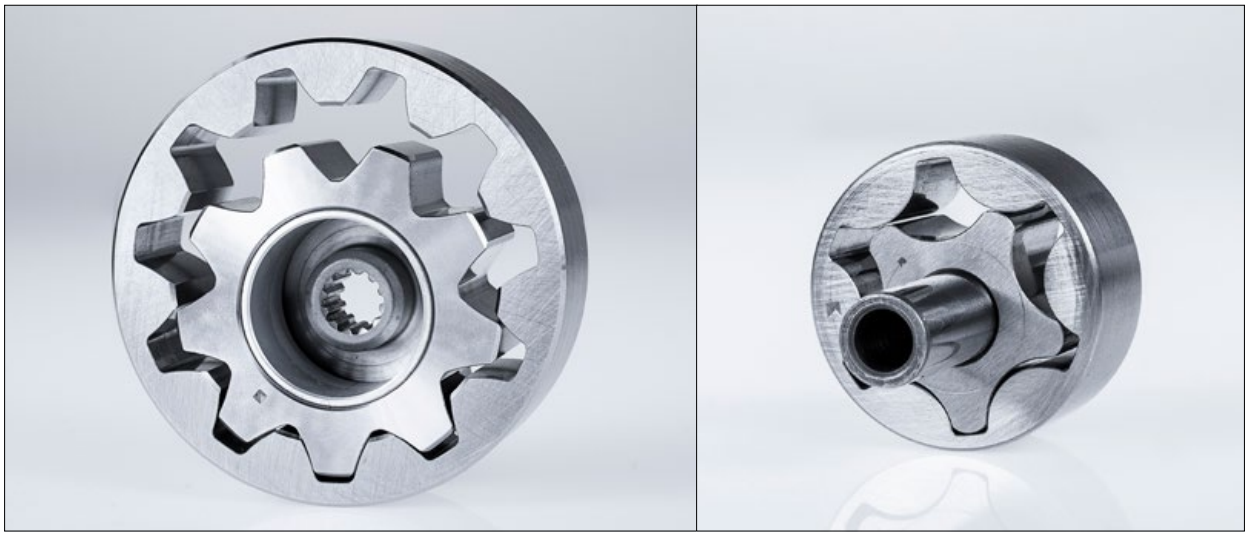

Fig. 8 Internal gear pump components produced by SHW Automotive (Courtesy SHW)

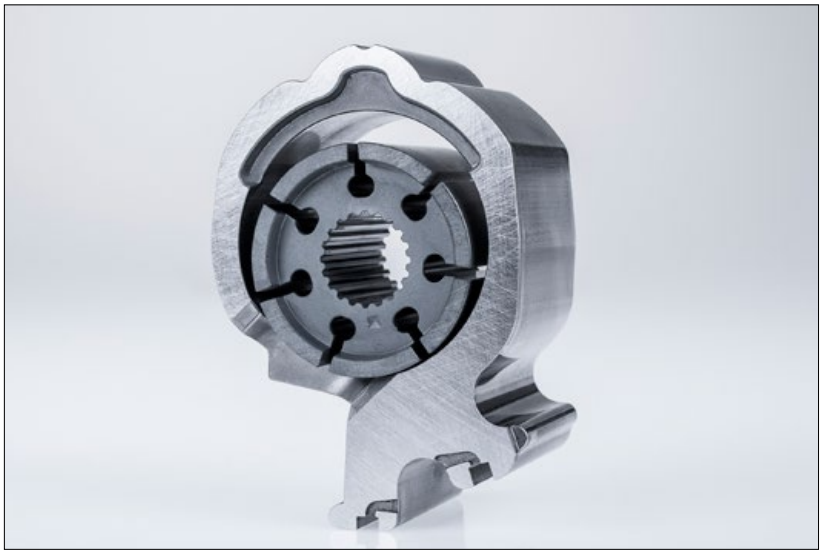

Fig. 9 Variable vane pump with rotor and housing designed for PM (Courtesy SHW)

Fig. 10 Camshaft phaser stator and rotor (Courtesy SHW)

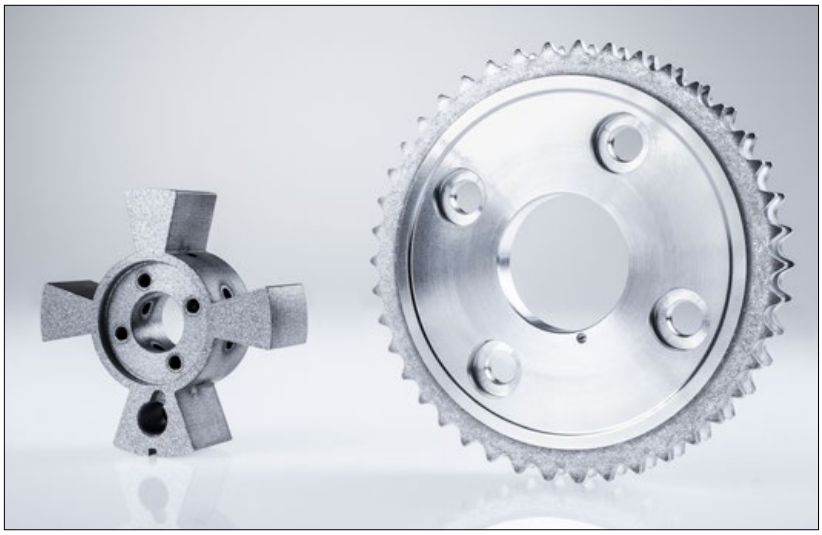

Fig. 11 Cam-phaser parts from sintered aluminium (Courtesy SHW)

Variable vane pumps

Variable oil pumps save energy because they always deliver the correct amount of lubricant according to engine demand. Variable vane pumps have an eccentric rotor with radial slots inside a cylindrical housing (Fig. 9). Vanes are mounted inside the slots that are pressed against the housing by springs, centrifugal forces or servo discs on the side faces. This creates the pump volume. Input and output of the oil is in the radial direction.

Variable vane pumps provide a very uniform flow of oil. They are so designed that the rotor position can be shifted towards the centre of the housing. This reduces the amount of oil that is pumped.

Pendulum bar pump

A pendulum bar pump is similar as a rotary vane pump, but it has bars which are fixed in an outer ring inside the housing and the other end is held by somewhat broader slots in the rotor. This concept has found little usage due to relatively high cost and energy consumption.

Camshaft phasers

Parts for camshaft phasers are another core competence of SHW (Fig. 10). These components are mounted on the camshaft and serve to vary the ignition timing depending on the speed and load condition of the engine. The engine can be run more efficiently with less emissions at partial or full loading. This serves to reduce the fuel consumption and consequently the amount of green-house gas emissions Further advantages are a higher torque and better idle stability.

Sintered aluminium parts

Sintered aluminium parts offer distinct advantages as they result in lower weight components. For rotating parts, it is not only the lower weight that requires less driving energy, but more important is the lower torque of the reduced mass.

In 2010, SHW Automotive received an Excellence in Powder Metallurgy Award from the European Powder

Fig. 12 Split gears, parts of the valve train (Courtesy SHW)

Fig. 13 Helical gears for the camshaft drive (Courtesy SHW)

Metallurgy Association (EPMA) for the development of their aluminium sprocket and rotor (Fig. 11). The rotor and sprocket are used in an automotive camshaft phaser application and were the first known components being manufactured from aluminium powder in large scale production. Compared to a standard sintered iron cam-phaser design, weight is reduced from 900 g to 450 g. The reduced weight and lower inertias improve the dynamic response behaviour of the cam-phaser, thus giving another benefit to engine performance and efficiency.

Split gears

The split gears shown in Fig. 12 are used as scissor gears in a camshaft drive. The spring-preloaded gears eliminate the clearance between the tooth flanks, avoiding any rattling noise.

Helical gears

Helical gears, a challenge for PM technology, are also successfully produced by SHW, as shown in the example of Fig. 13.

SHW's commitment to education and training

Southern Germany is a region with a very strong industrial structure where unemployment is low and where it is hard to find skilled staff. Therefore education and training of technical personnel has become a high priority at SHW and currently 22 young people are in apprenticeship, mainly industrial mechanics. Two of these combine their industrial training with a university education, whilst the majority of the technical personnel, in particular press setters, are trained in-house. Consequently, SHW has a strong interest in ensuring that engineers and technicians stay with the company for a long time.

External training is embedded in the long-term oriented employee development training program. Short courses in metal powder processing are offered by the EPMA and other organisations. SHW also takes part in these courses in order to broaden the PM knowledge of its staff.

Outlook

SHW is at the forefront of technical development in engine and transmission pumps and a key supplier to the global automotive industry. With tighter environmental and regulatory requirements in the automotive sector, the company's focus on developing products that contribute to a reduction in fuel consumption and resulting CO_2 emissions will allow SHW to meet these demands. Oil pumps and camshaft phasers are becoming more complex and SHW is committed to growth through continued research and ongoing development of its products.

With its broad range of products for the engine and transmission periphery and its new strategic facilities in relevant markets worldwide, SHW is well positioned to benefit from market trends and the global demand for mobility. Process improvement, capacity expansion and an optimised international production network are intended to help satisfy the requirements of automotive customers and to boost the company's competitiveness. By providing innovative solutions for all powertrain concepts the company is optimistic for future growth.

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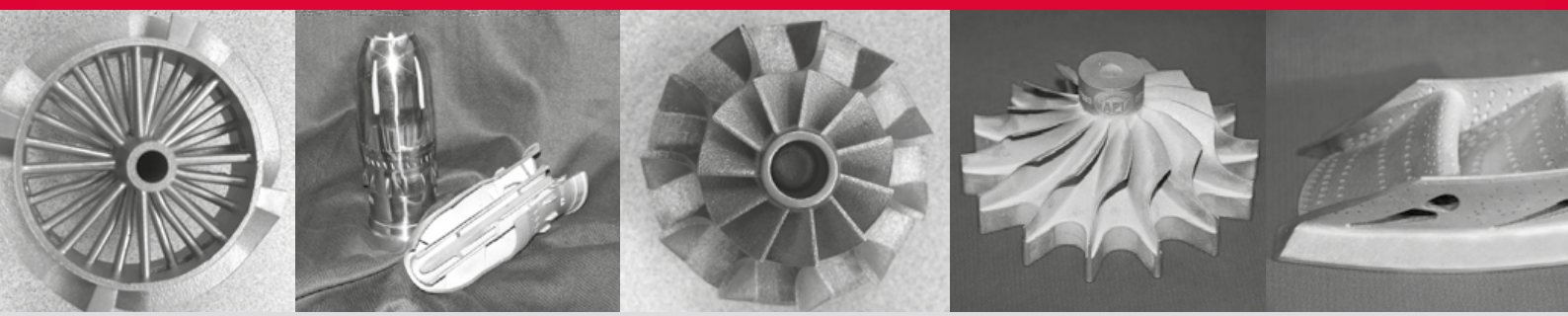

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Combining Hot Isostatic Pressing and heat treatment: An elegant way to streamline the supply chain

Combining HIP and heat treat into a single, integrated, process offers end-users an elegant way to streamline their supply chain while also decreasing shipping and handling, decreasing energy consumption and improving the delivery time for metal parts that require both HIP and heat treatment. Continued improvement in HIP equipment from the 1970s to the present day has offered the processor and the end-user increasingly advanced process options with a recent development providing a dramatic boost in what an integrated HIP and heat treat process can deliver. Dr Stephen J Mashl reports on the state of this game-changing development.

A356 aluminium, Mar-M247 nickel-based superalloy, Ti-6Al-4V, Grade 91 steel, 2205 duplex stainless steel and CPM15V Tool Steel are six metal alloys that are vastly different in properties and application yet all have two things in common. Firstly, they are often HIPed and secondly, they are typically heat treated before going into service. Hot Isostatic Pressing (HIP) is a high temperature pressure treatment. For cast alloys such as the A356 aluminium or Mar-M247, the HIP process is employed to eliminate the microporosity that develops from shrinkage and decreasing gas solubility during solidification. The other alloys listed are often HIPed as powders where the HIP process is used to transform the powder into a fully dense solid, either in the form of a simple billet or, using advanced HIP PM techniques, a complex net- or near-net shape.

When HIPing cast alloys, it is not uncommon to pause during heating, introducing an isothermal hold at some temperature below the final soak temperature, in order to allow a segregated casting to homogenise and thus avoid incipient melting during the final heating segment. In this situation, it could be said that a homogenisation anneal was integrated into the HIP cycle but more advanced heat treating is possible. As

Fig. 1 MIM 17-4PH turbocharger impellers are a prime candidate for integrated HIP and heat treat. These components operate under demanding high temperature, high strain conditions and thus, are commonly HIPed to remove microporosity and subsequently heat treated to achieve optimal mechanical properties

Alloy	Typical HIP temperature	Published heat treat conditions
A356 Aluminum	505°C – 520°C	Solution treat 540° for 12 hours Water quench Age at 155°C for 3-5hr.[1]
Ti-6-4	900°C – 950°C	Solution treated 955 – 970°C Water quenched Aged at 480 – 760°C for 2-8 hr.[1]
Mar-M247	1185°C – 1200°C	Solution treated 1225- 1250°C Quench Age 870°C.[2]
2205 Duplex Stainless Steel (UNS S31803)	1160°C	Anneal 1020 – 1100°C Rapid cool[3]
CPM 15V	1120°C	Austenitize 1065-1175°C for 20–30 min. Quench Double Temper 540°C – 2 hrs[4]
H13 Tool Steel	1120°C	Austenitize 1,020-1,030°C Quench Temper 250°C [5]

[1] *ASM Metals Handbook*, 9th edition, vol.4, American Society for Metals, Metals Park, Ohio, 1981.
[2] G. Janowski, The Effect of Tantalum on the Structure/Properties of Two Polycrystalline Nickel-base Superalloys: B1900+Hf and Mar-M247, NASA Contractor Report 17847, 1985
[3] Otukumpu Duplex Stainless Steel Data Sheet
[4] Crucible Industries CPM15V Data Sheet
[5] Bohler-Uddeholm H13 Data Sheet

Table 1 Comparison of HIP and heat treat conditions for selected alloys

shown in Table 1, the temperatures at which many alloys are HIPed are very close to the temperatures at which those alloys are austenitised, solution heat treated or annealed. The dwell time at temperature during HIP is often sufficient to complete the first step of a heat treat sequence and if the parts can be cooled with sufficient rapidity, i.e., quenched within the HIP unit, then subsequent aging or tempering can be performed as a follow-on process. Conventional practice often has the HIP and heat treat processes performed at different facilities, thus the parts must be loaded and unloaded into process vessels twice and shipped from one facility to another. Combining HIP and heat treat is a simple, elegant, method by which the desired structure and properties can be achieved while providing a way for an end-user to streamline their supply chain while decrease processing costs and energy consumption.

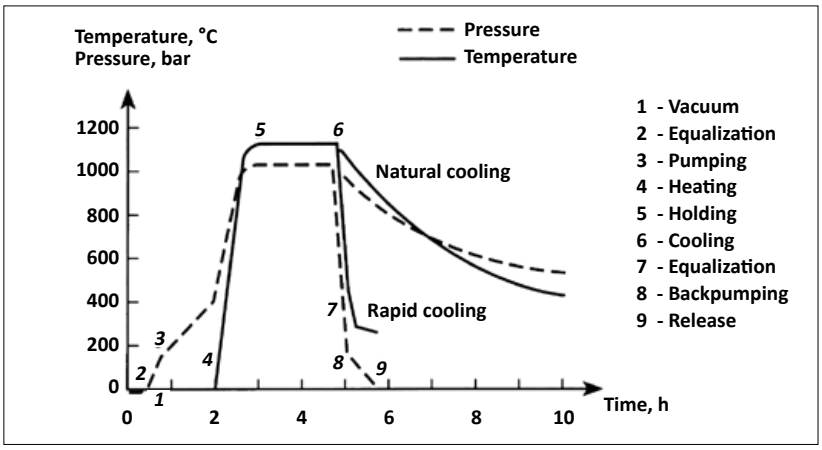

Fig. 2 A schematic showing the temperature –pressure profiles of a conventional cool HIP cycle and a rapid cool cycle. The development of uniform rapid cooling capabilities in the 1980s offered the HIP operator the possibility of cutting floor-to-floor processing times by approximately 50%. Rapid cooling also offered the potential to quench within the HIP unit (After Bergman and Skogman [3])

Combining HIP and heat treatment

The HIP process evolved from a development project in the 1950s, becoming commercialised in the 1960s and 1970s and reaching a point in the 1980s where growing demand for HIP processing and dissatisfaction with long cycle times drove the development of a new generation of HIP equipment having rapid cool capabilities. An older HIP unit might require two to three hours to reach temperature and pressure set-points followed by a one to four hour soak.

The final cooling and depressurisation segment of the HIP cycle could take five to seven hours, consuming as much time as the other two process segments combined. As shown in Fig. 2, the introduction of rapid cooling dramatically decreased overall cycle times. While rapid cooling was introduced as way to increase productivity, engineers soon began to consider the rapid cool capabilities of the new HIP equipment from a standpoint of quenching and heat treating.

Cast nickel-based superalloys

Nickel-based superalloys are highly corrosion resistant metal alloys that also have excellent high temperature properties and thus are heavily used by the aerospace industry in the production of disks (such as that shown in Fig. 3a), blades and vanes for use in gas turbines. These components are manufactured in cast, wrought and Powder Metallurgy forms. Given the life-critical nature of many of the applications and the need to maximise mechanical properties for operation in very

Fig. 3 A nickel-based superalloy component like the turbine disk, (a), is put through a solutionize-quench-age heat treat process in order to produce the highly desirable γ + γ′ microstructure shown on the right, (b). (Images after Orsal [6], and Linköping University [7])

aggressive environments, components made from these alloys are frequently HIPed.

The heat treating of nickel-based superalloys is a precipitation hardening process where the alloy is heated to an elevated temperature to form a single phase, γ, solution, quenched, and then aged at a lower temperature to drive the formation of the γ′ precipitates that act as a barrier to dislocation movement. The resultant dispersion of γ′ in a γ matrix, such as that shown in Fig. 3b, is primarily responsible for these alloys superior high temperature properties.

Nickel-based superalloys are prime candidates for an integrated HIP plus heat treat approach. In 1980, in what may be the first documentation of a combined HIP and heat treat process, Lamberigts, *et al.* present a study on the HIP of Inconel and Mar-M nickel-based superalloys, noting that "If HIP is carried out at a high enough temperature, HIP cycles can lead to chemistry homogenisation without deleterious second phase coarsening, provided the cooling sequence is sufficiently rapid." These authors state that higher HIP pressure helps to homogenise the gamma prime precipitate distribution, an issue that will be brought up again in this paper, and note that reduced time at elevated temperature is beneficial to structure and properties citing advantages of an integrated process as being reduced cost, reduced scrap rate, better materials utilisation and high dimensional and surface quality [1]. As shown in Fig. 4, the net effect of an integrated HIP and heat treat procedure was improved minimum and average property values with decreased statistical scatter indicating that the combined HIP-heat treat process provided significant improvement in the parts practical reliability.

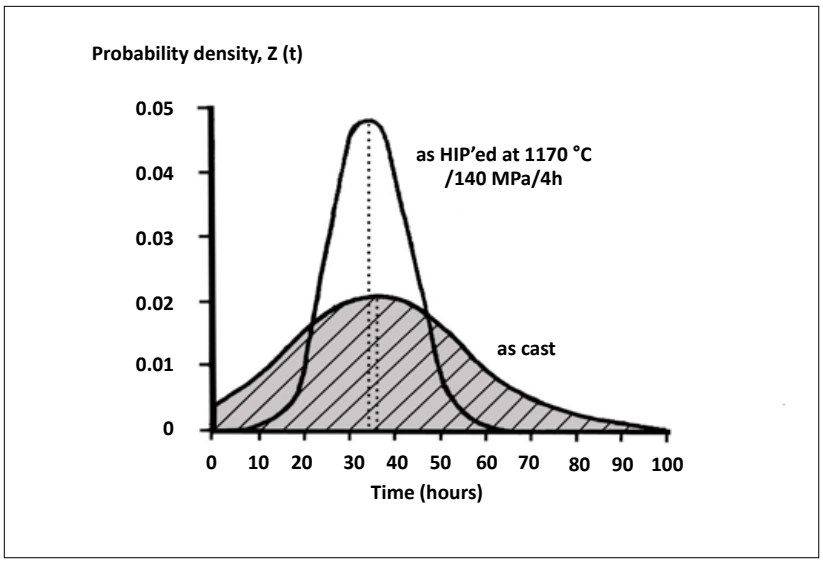

Fig. 4 The influence of HIP on the probability density function of creep lives of Mar-M-002 turbine blades. The narrower, taller bell curve that describes the as-HIPed specimens indicates a significant improvement in the parts' practical reliability. HIP improved both the minimum and average property values while also decreasing statistical scatter of Mar-M-002 alloy blades. Testing performed at 760°C/695 MPa (1400°F/100 ksi). (After Lamberigts et al. [1])

In the late 1980s, ASEA Brown Boveri, Ltd. (ABB) introduced a new generation of HIP equipment having uniform rapid cool (URC) capabilities. As shown in the schematic in Fig. 5, this equipment introduced a fan, a heat exchanger and a cleverly designed thermal barrier that allows a controlled portion of the circulating furnace atmosphere

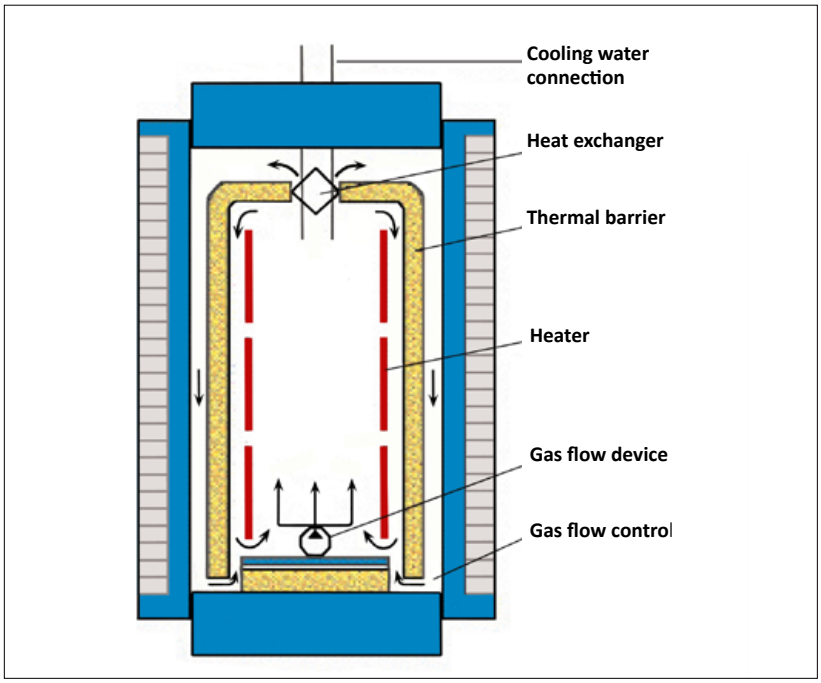

Fig. 5 A schematic of a uniform rapid cool (URC) HIP unit. The design was developed by ABB (now Quintus Technologies) in the 1980s in order to rapidly cool a load of parts after the dwell segment of the HIP cycle was complete. The design includes a gas flow device (a fan) located in the bottom zone region of the HIP unit that circulates the gas within the vessel. The forced convection, key to rapid cooling, also promotes temperature uniformity within the HIP unit. A heat exchanger resides at the top of the thermal barrier providing cooling to the gas within. In addition, the flow of gas is controlled such that a portion of the atmosphere circulates outside the thermal barrier, cooling as it comes in contact with the water-cooled pressure vessel. (After Zimmerman and Toops [8])

Fig. 6 A 350 kg duplex stainless steel PM valve body produced using hot isostatic pressing near net shape technology. The internal channel network is formed as part of the HIP process. Valve body height is approximately 600 mm (Photo courtesy of Bodycote Powdermet AB)

to come into contact with the inner wall of the water-cooled pressure vessel, further chilling the hot gas within the HIP unit. Bergman, Westerlund, Zimmerman and Skogum published papers on this technology during the early 1990s, further examining the potential to heat treat nickel-based superalloys as well as high speed steels within the HIP unit using the rapid cool capability of the new generation equipment [2-5].

Powder Metallurgy duplex stainless steels

Duplex stainless steels (DSS) are a class of stainless steels that have microstructures containing fractions of both austenite and ferrite, the level of austenite typically ranging from 45 to 60 volume percent [9]. This alloy class is known for possessing excellent strength and toughness while also exhibiting resistance to stress corrosion cracking in chloride environments, and pitting. As a result of this combination of properties, these alloys fill a performance gap between austenitic stainless steels and nickel-base superalloys and are heavily used in off-shore oil and gas production [10-12].

Duplex stainless steel components may be manufactured by casting, forging, or using Powder Metallurgy techniques. Of those process options the HIP PM approach produces a fine grained, equiaxed microstructure, delivering isotropic mechanical properties that generally exceed those of a forging while far surpassing those of castings. The PM valve body shown in Fig. 6 is typical of the components that can be fabricated using HIP near net shape technology[13].

One obstacle in manufacturing large HIP PM components from duplex stainless steel is that the relatively slow cooling rates typical of a conventional HIP cycle result in the formation of brittle intermetallics on slow cooling [12]. Of these detrimental precipitates, the iron and chromium rich sigma phase presents the greatest problem [10,14] while a much finer coherent

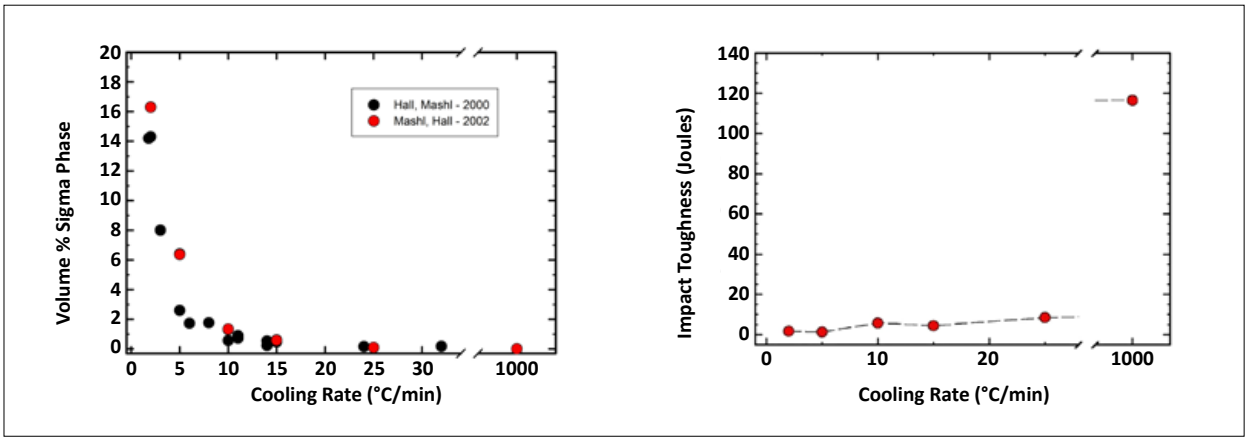

Fig. 7 A plot showing the concentration of sigma phase within HIPed P/M Duplok 27 samples as a function of the cooling rate within the core of the sample (left), and fracture toughness as a function of cooling rate from the 2002 study [17]. The 1000° data point is from a water-quenched specimen, other data is from either HIP-Quenched or gas-quenched specimens. While sigma phase was effectively eliminated from the samples cooled at 25°C/minute or faster. All gas-quenched and HIP-quenched specimens displayed poor fracture toughness

precipitate, α′, can form at lower temperatures causing 475°C embrittlement. The conventional solution to this problem is a post-HIP solution heat treat followed by a rapid quench. The potential benefit of an in situ solution heat treat within the HIP is obvious and between 2000 and 2002, Mashl and Hall conducted studies examining that possibility [15-17]. Employing a mix of conventional and rapid cool HIP units as well as in-lab gas quench capabilities, multiple samples of a superduplex stainless steel alloy were either HIP- or gas-quenched at cooling rates ranging from 1°C/min. to 32°C/min. The effect of gas quenching on the concentration of sigma phase is shown in Fig. 8 and compared to water-quench data (1000°C/min.). While the faster cooling rates effectively eliminated sigma phase, the fracture toughness of the HIP- and gas-quenched specimens fell far short of that for the water quenched material, as shown in Fig. 7. Subsequent fractography indicated ferrite embrittlement thus the authors concluded that while the cooling rates achieved were adequate to avoid sigma phase formation, the rates where not sufficiently rapid to avoid alpha prime precipitation and 475°C embrittlement.

Cast aluminium alloys

Between 2002 and 2007, Diem, Mashl, Sisson and Bernard together studied the potential for combining the HIP and heat treat of aluminium castings into a single process using the A356 aluminium alloy as their test material [18-21]. As indicated in Table 1, the HIP and solution heat treat temperatures used for this alloy are sufficiently close to consider a combined process. However some heat treat specifications published for this alloy require a 10 - 12 hour hold at the solutionising temperature. Development work has shown that with modern alloys and improved processing, shorter soak times are possible in some cases. Thus as detailed in a summary published by Mashl and Diem [21] and shown in Table 2, the researchers compared integrated HIP and solution heat treat processes using 4 and 10 hour holds to conventional,

Description	Processing
As-Cast and T6 heat treat (baseline)	Cast Solution Heat Treat: 10 hours at 538°C Water quench Age: 4 hours at 155°C
Discrete HIP and T6 heat treat	Cast HIP (Densal®) Solution Heat Treat: 10 hours at 538°C Water quench Age: 4 hours at 155°C
Combined HIP + 4 hr. solution heat treat, quench and age	Cast Combined HIP (Densal®) + solution heat treat for total of 4 hours at 538°C Water quench Age: 4 hours at 155°C
Combined HIP + 10 hr. solution heat treat, quench and age	Cast Combined HIP (Densal®) + solution heat treat for total of 10 hours at 538°C Water quench Age: 4 hours at 155°C

Table 2 Experimental conditions used in a study examining the integration of HIP and heat treat for aluminium alloys

discrete, HIP and heat treat and to cast plus heat treat, i.e., without HIP. Given the need to achieve water-quench cooling rates the integrated HIP and heat treat cycles began as a standard HIP cycle however once the pressure segment of the soak was complete, furnace power remained on during depressurisation, maintaining the castings at the desired soak temperature for the full allotted time. Once the desired time at temperature had passed (either 4 or 10 hours) the castings and support tooling was unloaded hot and water quenched.

In a first round of experimental work performed using commercial A356 aluminium castings as test specimens, the researchers found that a high concentration of thin oxide defects dominated tensile and fatigue properties, the detrimental effect of these oxides overwhelming any benefit that could come from HIP. A second round of experiments using cast wedge shaped specimens, melted and poured under conditions that would minimise oxides in the castings yielded the excellent results that follow. Average tensile properties from the second set of trials are listed in Table 3. As can be seen, all specimens exhibited superb strength and ductility considering that many process specifications call for a minimum ductility level of 7% elongation in this cast alloy. The lack of improvement in tensile properties with HIP was attributed primarily by the fact that the simple as-cast shape contained very little porosity, a tribute to good foundry practice and the simple, easily cast, shape.

Fatigue life is sensitive to very small amounts of residual porosity as the data in Fig. 8 shows. In contrast to the tensile data, the fatigue test results showed significant differences between the specimens processed using the four different methods. In summary, this research project showed that an integrated HIP plus heat treat process was viable for aluminium castings, either by quenching within the HIP unit, provided the HIP unit could cool at a rate that was sufficient to satisfactorily quench the product after solutionising or by a rapid, hot transfer of the product to a conventional furnace, followed by water quench. The improvement in fatigue life that was observed in specimens where a portion of the solution heat treat process had been carried out at HIP pressures was not explained however, based on the data presented here, it appears that a combined HIP and solution heat treat process could offer significant property and performance improvements in addition to the benefits to supply chain and productivity. More research is needed.

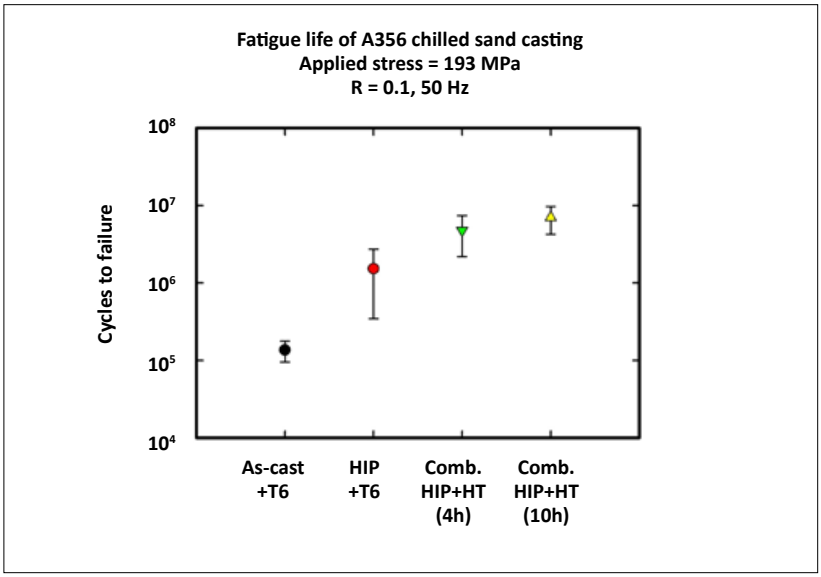

Fig. 8 Average fatigue life as a function of processing route for Sr-modified A356 aluminium sand castings. Typical secondary dendrite arm spacing ranged from 35-45μm. Testing was performed at 193 MPa maximum stress, R=0.01, 50Hz with a sinusoidal waveform. Seven to nine specimens were tested under each set of processing conditions. The processing conditions were, from left to right on the x-axis, conventional cast followed by conventional T6 heat treat, discrete HIP followed by conventional T6 heat treat and two integrated HIP plus heat treat cycles, one with a total of 4 hours at the solutionising temperature, the second with 10 hours spent at the solutionising temperature. The data points represent average values from seven to nine specimens processed under each set of conditions. It should be noted that two specimens from the combined HIP plus heat treat - 4 hour hold and four specimens from the combined HIP plus heat treat – 10 hour hold achieved run-out, i.e. those specimens survived 10 million cycles without failing. Error bars represent 95% confidence limits

Process specification	0.2% Yield strength MPa (ksi)	Ultimate strength MPa (ksi)	Elongation %	Reduction in area %
T6	192.4 (27.9)	287.5 (41.7)	17.2	24.0
Densal, T6	187.2 (27.2)	287.5 (41.7)	17.2	23.9
4-H, T6	189.5 (27.5)	289.2 (42.0)	16.4	21.3
10-H, T6	196.8 (28.5)	298.2 (43.3)	17.2	20.2

Table 3 Average tensile properties of Sr-modified A356 sand castings

Gas quenching at HIP pressures

It should be apparent from the three aforementioned examples of integrated HIP and heat treat, that the ability of HIP system to cool the material within the pressure vessel at a sufficiently rapid rate is a key factor to success. The cooling rates must be fast enough to avoid the undesired phase transformations that accompany slow cooling in heat treatable alloys, yielding the desired metastable solid solution necessary for a subsequent aging, tempering, or precipitation hardening treatment.

High pressure gas quenching

High Pressure Gas Quenching (HPGQ) is a technology that has been seeing increased penetration within the commercial heat treat market. Operating at pressures of 5 – 20 bar, the advantages of HPGQ have been well characterised. As illustrated in Fig. 9, in a conventional liquid quench system, i.e., water, oil, etc., the interaction between the hot part and the liquid quenchant is characterised by three stages, initially a continuous insulating vapour barrier is formed and cooling is slowed, the second stage consists of nucleate boiling with very rapid heat transfer and, finally, convective cooling after boiling ceases with a relatively moderate cooling rate. As shown in the gear drawing in Fig. 10, complex parts can have all three of these mechanisms active at the same point in time thereby creating large, non-uniform thermal gradients in the parts which can lead to distortion. In contrast, quenching in a high pressure gas environment is characterised by a constant heat transfer coefficient and, as a result, offers a higher degree of cooling uniformity and minimal distortion. Gas quenching is also inherently cleaner than an oil quenching.

Given the benefits of gas quenching, there has been continuous interest in expanding gas quenching capabilities within industry. Driven by this, there has been a move toward higher quench

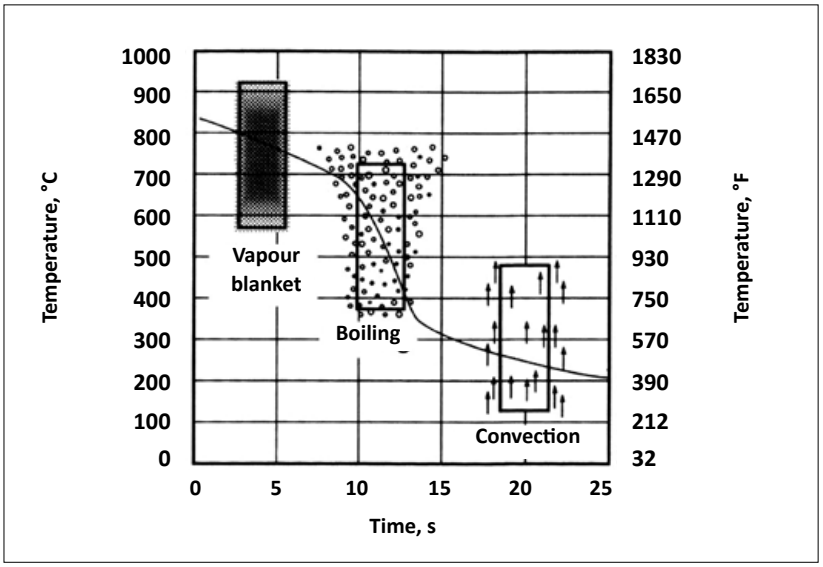

Fig. 9 Cooling rate and cooling mechanisms as a function of time for a 25 mm (1") diameter steel bar in still water. Upon initial quenching a continuous insulating vapour barrier is formed and cooling is comparatively slow. Once the vapour barrier breaks up and boiling begins cooling accelerates until boiling stops and cooling slows as convection drives the final cooling. (After ASM Handbook, Vol. 4 Heat Treating)

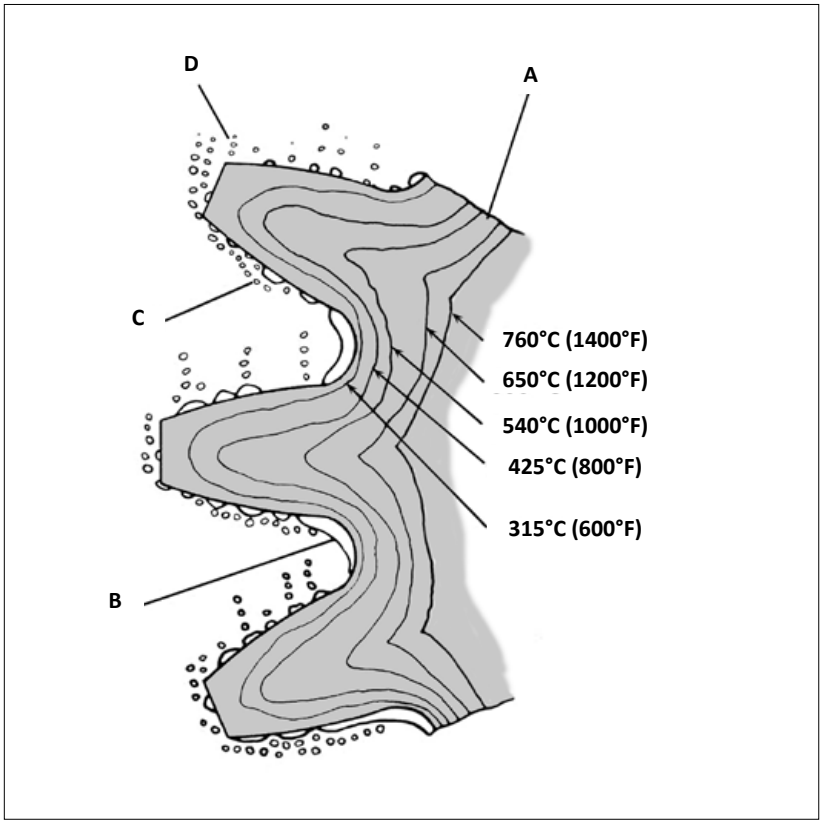

Fig. 10 A drawing showing the thermal gradients within a gear section and the mechanisms by which distortion occurs during liquid quenching. Trapped vapour adjacent to the gear surface either as a vapour barrier (point B) or as trapped bubbles (point C) slow cooling while escaping gas bubbles (point D) accelerate cooling. The net result are the asymmetric thermal gradients within the gear (point A) (After ASM Handbook, Vol. 4 Heat Treating)

pressures. Where early high pressure gas quench equipment operates at nominal 5 bar pressures, newer units are capable of quenching at 15-20 bar pressures. This improvement, combined with advances in heat exchangers and higher gas velocities through the cooling chamber has resulted in an improved ability to extract heat from the parts being quenched.

The rate at which heat can be removed from a part during quenching is controlled, in part, by the ability to transport heat across the interface that is the surface of the part and the surrounding quench environment, i.e. water, oil, gas etc. This phenomenon is characterised by the heat transfer coefficient (also called the film coefficient). As illustrated in Fig. 11, the heat transfer for any given gas increases with increasing pressure thus increasing the gas pressures within the quench chamber improves the system's ability to extract heat from the parts within.

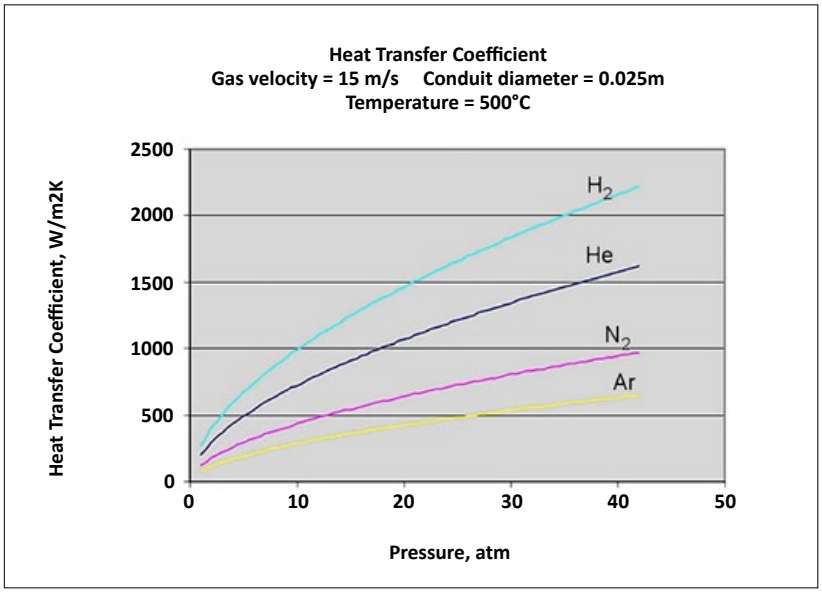

Fig. 11 Theoretical relationship between the heat transfer coefficient and pressure at 500°C and 15 m/s for hydrogen, helium, nitrogen and argon. (After Lin [26])

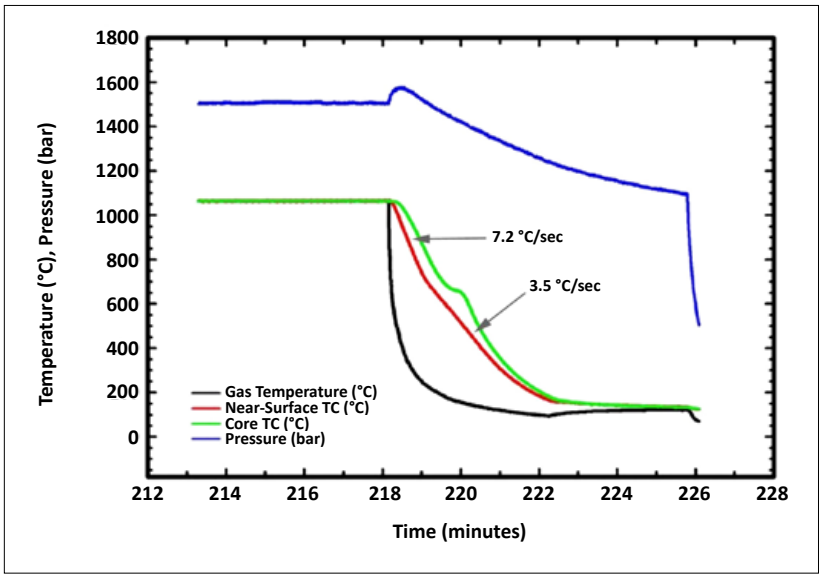

Fig. 12 Temperature and pressure profiles of the cooling-depressurization portion of the URQ HIP cycle for a 51mm Ø x 150mm cylindrical steel sample. The line indicating the gas temperature reflects the temperature of the HIP atmosphere. Near-Surface TC and Core TC data represent the temperature of the sample at those locations as measured by embedded thermocouples

A breakthrough in gas quenching at HIP pressures

While the rapid cooling capabilities of HIP units have improved over the years, a recent advance offers a dramatic leap forward. Quintus Technologies AB (previously Avure Technologies AB) has recently introduced a new system that they have named the Uniform Rapid Quench (URQ) HIP system. These systems are reported to be capable of cooling at rates exceeding 1000°C/minute and further, to perform this cooling while maintaining the pressure within the HIP vessel at or near conventional HIP pressures [22-25]. Thus, while current, commercial, high pressure gas quench systems can quench at pressures up to 15 – 20 bar, the URQ systems are reported to quench at pressures of 1000 – 2000 bar.

In 2015 the author, working with Quintus, set out to characterise the heat treat capability of a URQ HIP system by using a URQ HIP unit to heat treat AISI 4140 steel, a common, high strength, low alloy steel that is frequently heat treated commercially [27]. With an abundance of data on the quench and temper response of this steel alloy, it was felt that the data generated from HIP-quenching experiments using this new URQ HIP system could be compared to data from conventional water- and oil-quench data thus providing a semi-quantitative assessment of the URQ HIP system. The experimental work employed cylindrical 4140 steel specimens having a diameter of 51 mm and a height of 150 mm. Select specimens were drilled longitudinally to allow the insertion of two thermocouples, one near-surface, the other on the centre line, to allow the monitoring of the core and near-surface tempera-

tures within the samples during quenching. The HIP cycle for the integrated HIP plus 1500 bar quench cycle was as follows:

- Ramp from room temperature and atmospheric pressure to 1065°C (1950°F) and 1500 bar (22,000 psi)
- Hold at 1065°C and 1500 bar for 2 hours
- Quench as rapidly as possible within the HIP unit while maintaining the gas pressure as close to 1500 bar as possible.

In addition, identical specimens were heated to the HIP temperature in an air atmosphere muffle furnace, held for two hours and then either water or oil quenched. Disk shaped specimens were cut from the central region of the cylinders. Specimens quenched using each of the three methods were polished, the microstructure was characterised and the hardness profile from the near-surface to the core of URQ-HIP quenched, water- and oil-quenched specimens was measured and compared.

A temperature-pressure profile from the quench portion of one URQ HIP cycle is shown in Fig. 12. As can be seen in that figure, the gas pressure remained above 1200 bar during the quench, however the centre line and near surface thermocouples embedded within the steel sample indicated that the bar itself cooled much slower that the HIP atmosphere. Oil quenchants are published to cool, on average, at rates of approximately 30-45°C/sec [28]. After observing the data shown in Fig. 12, indicating that a URQ test specimen cooled at an initial rate of 7.2°C/sec, then slowing to 3.5°C/sec, it was assumed that the URQ quenched steel would display a structure and properties appropriate to slower-than-oil cooling. The actual results were surprising.

The microstructures of the water quenched 4140 steel specimen was fully martensitic, the oil quenched specimen was predominantly bainitic, and the URQ quenched specimen was intermediate, exhibiting a structure that was primarily martensite with a small amount of bainite. The hardness data, shown in Fig. 13, corresponds to the metallographic results with the hardness profile of the URQ HIP-quenched specimen displaying hardness values that exceeded those of the oil-quench specimen while approaching that for the water quenched steel.

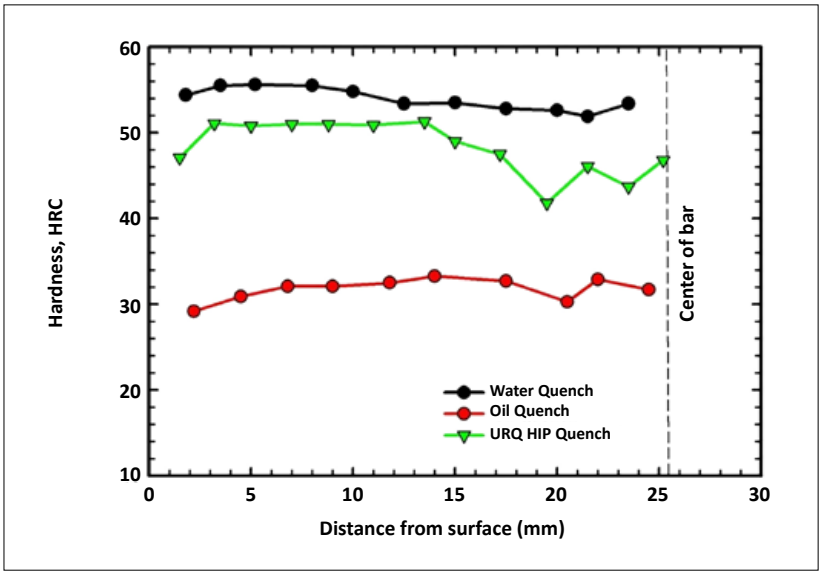

Fig. 13 A plot of hardness (HRC) versus distance from the surface showing the hardness profiles for water quenched, oil quenched and URQ HIP quenched specimens. The drop in hardness in the near surface regions is attributed to decarburization. The severity of the URQ HIP quench falls in between that of the water and oil quench

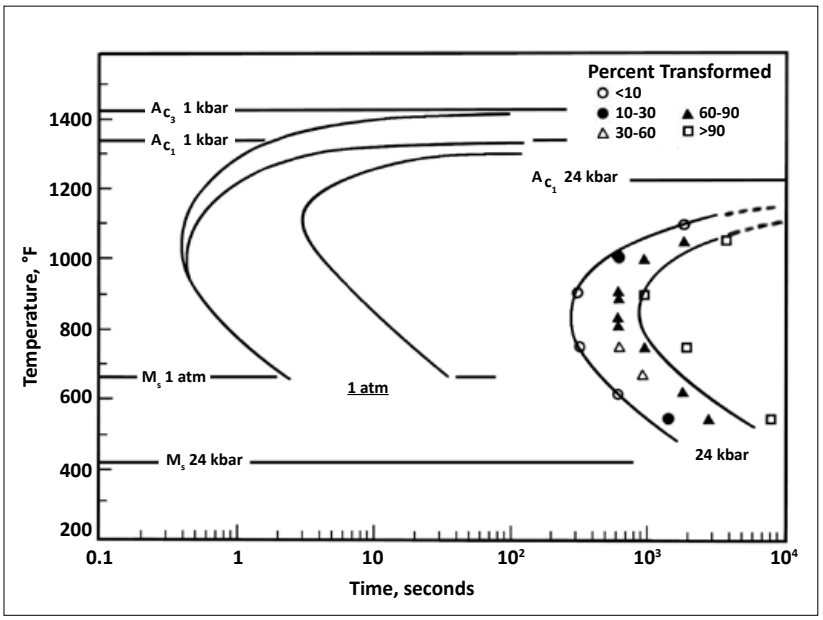

Fig. 14 An isothermal transformation diagram for 1040 steel at 0.1 MPa (1 atmosphere) and 2400 MPa (After Nilan [30])

Taken together, the data appears contradictory or at least confusing. How is it possible that the URQ HIP-quenched specimen could cool at a slower rate yet display hardness values and microstructural features associated with a higher cooling rate? An explanation can be found if one examines the effect of pressure on the kinetics of the $\gamma \rightarrow \alpha + Fe_3C$

transformation. Research performed in the 1960's indicates that increased pressure tends to stabilise austenite, retarding the $\gamma \rightarrow \alpha + Fe_3C$ transformation and lowering the martensite start temperature [29-34]. The isothermal transformation diagram shown in Fig. 14 illustrates how, with increased pressure, the martensite start temperature is lowered and the pearlite and bainite transformations are slowed. While the HIP pressures employed in these experiments do not approach that presented in Fig. 14, the relative influence of pressure on the phase transformations does explain the behaviour observed in these trials.

Summary

Lamberigts, *et al.*, noted in their 1980 paper that the use of a rapid cool HIP system to perform a solutionise and quench heat treatment within the HIP unit was beneficial to dimensional control, surface quality and the structure and properties of cast nickel-base superalloys while also offering reduced cost, reduced scrap rate, improved materials utilisation and high dimensional control and good surface quality. These same benefits appear to be available to producers and consumers of other metal alloy components. Past work has shown that cast aluminium alloys are well suited to an integrated HIP/heat treat process. HIPed Powder Metallurgy duplex stainless steel components would benefit from a combined process if sufficiently rapid cooling rates can be attained.
The ability to achieve high cooling rates in the core of the parts being processed has been an obstacle and may continue to be so, especially given the large size of some HIP PM products. However, the URQ HIP technology recently developed by Quintus Technologies offers rapid cooling at HIP pressures and given the beneficial effect of elevated pressure on the heat treating of ferrous alloys, uniform rapid quench offers a significant advance in the ability to merge HIP and heat treat into a single process for iron-based alloys. Researchers in Sweden and Germany are already presenting new information and technical breakthroughs [35-37].

Beyond the observed advantages for ferrous alloys, Lamberigts noted a beneficial effect of pressure on the solution heat treat of nickel-based super alloys. The Diem, Mashl, Bernard, Sisson effort toward combining the HIP and heat treat of aluminium alloys indicated that improved fatigue performance may be attainable when solution heat treat is performed at elevated pressure. More research in this area is certainly needed but the future for combined HIP and heat treat looks very promising.

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Powder Metallurgy in India: New applications for Powder Metallurgy at PM-16

The PM-16 International Conference & Exhibition on Powder Metallurgy and Particulate Materials and the 42nd Annual Technical Meeting of PMAI, organised by the Powder Metallurgy Association of India (PMAI), took place at the Hyatt Regency in Pune, India, from February 18 - 20, 2016. In his report for *Powder Metallurgy Review*, Professor Ramamohan Tallapragada, PM Consultant, Mumbai, India, provides an overview of the conference and highlights new applications for metal powder technology discussed at the event.

The PM-16 conference and exhibition was held in Pune, India, the second largest city in Maharashtra after the state capital Mumbai. Pune, recognised as one of the fastest growing cities in the Asia-Pacific region, is known for its manufacturing and automobile industries as well as for its numerous colleges, universities and research institutes. The city is home to the Automotive Research Association of India and all sectors of the automotive industry are represented, from motorcycles to cars and trucks. Automotive companies such as Tata Motors, Mahindra & Mahindra, Mercedes Benz, Force Motors (Firodia-Group), Kinetic Motors, General Motors, Land Rover, Jaguar, Renault, Volkswagen and Fiat have established facilities near Pune.

Each year, the Powder Metallurgy Association of India organises its popular conference and, each year, the event includes a wide variety of technical presentations. This year's conference included over 100 presentations, made in six plenary sessions and twelve parallel sessions. There were also a number of special interest sessions that showcased the latest in PM technology, equipment and services, as well as an exhibition of national and international PM companies and suppliers.

Fig. 1 The opening at PM-16 included the traditional lighting of the lamp ceremony (left to right: A Gore (Jt. Sec PMAI), Prof T R Rama Mohan (PM-16 Co- Chairman), N Gopinath (President PMAI) and Prof P Ramakrishnan (PM-16 Chairman)

Fig. 2 The President of PMAI, N Gopinath, discussed opportunities and challenges for PM in India

Fig. 3 C L Chu, President of TPMA, summarising the status of Powder Metallurgy in Taiwan

Fig. 4 Cesar Molins, Vice-President of EPMA presented an overview of the status and trends in the European PM Industry

Opening ceremony provides overview of the PM industry

The conference began with an Inaugural Ceremony in which the Conference Chairman, Professor P Ramakrishnan, welcomed delegates to PM-16 and discussed the importance of Powder Metallurgy as an alternative technology in the automotive, defence, aerospace, energy and engineering industries (Fig. 1). For the past 42 years, stated Ramakrishnan, the Powder Metallurgy Association of India (PMAI) has been promoting PM to academic institutes, R&D organisations and various PM Industries making metallic, ceramic and cermet powders and components. The PMAI organises short courses, thematic workshops and, of course, international conferences and trade exhibitions, stated Ramakrishnan.

Powder Metallurgy in India

The President of the PMAI, N Gopinath, in his welcoming address, gave an overview of Powder Metallurgy in India, identifying the opportunities and challenges to be met (Fig. 2). India is perhaps the world's largest tractor manufacturer, second largest two-wheeler and bus manufacturer, fifth largest heavy truck, sixth largest car and eighth largest commercial vehicle manufacturer. There are approximately 28 powder, 65 component and 52 equipment manufacturers helping to achieve estimated production of ferrous and non-ferrous components in 2015 of about 30,500 tonnes and 10,000 tonnes respectively. The country has many automotive manufacturers and there is an increasing emphasis on compact cars, stated Gopinath.

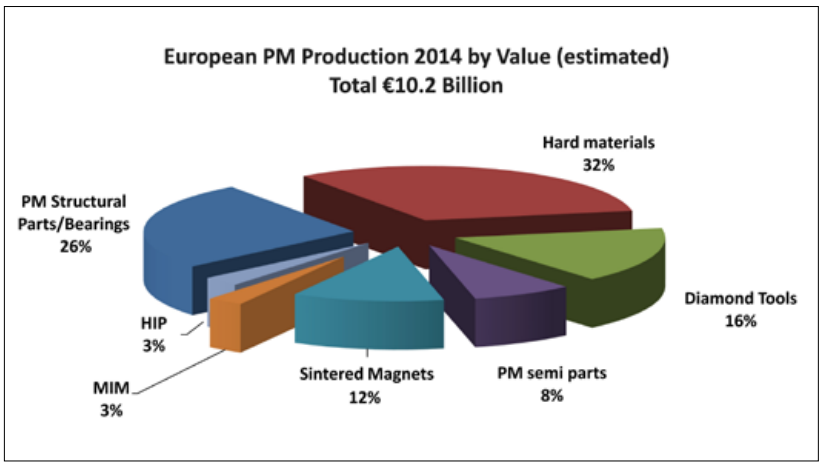


Fig. 5 Total European PM Production in 2014 by value was estimated to be €10.2 billion (Courtesy EPMA)

Powder Metallurgy in Taiwan

The plenary session continued with a presentation by C L Chu, President of Taiwan Powder Metallurgy Association (TPMA) that summarised the status of PM in Taiwan (Fig. 3). The market for PM in 2015 was around 31,955 metric tonnes, reported Chu, with approximately 60 producers contributing towards a growth rate of around 5-7% in the region. Even though over 85% of powders are imported, the Taiwanese PM industry offers advanced technology with low production costs. For the past 25 years, the MIM process has been used to produce parts used in mobile phones and 3C products, added Chu.

Around 44% of PM parts manufactured in Taiwan were used in the transport sector in 2015, stated Chu. The fact, that the auto industry in Europe and USA is keen to purchase parts from Asia and many PM

techniques are being recognised as green energy processes, is helping further progress of the PM industry in Taiwan.

Powder Metallurgy in Europe

Cesar Molins, Vice-President of the European Powder Metallurgy Association (EPMA), gave a presentation on the status and trends in the European PM industry (Fig. 4). He considered Europe to be in growth, although very small, at around 0.4%. Total European car production is recovering, he said, with about 15 million units produced in 2014, and PM parts per European car continued to increase to about 9.5 kg per vehicle. European PM Parts produced in 2014 totalled about 228,000 tonnes, with ferrous structural parts contributing 81%, nonferrous structural parts, HIP parts and hard materials parts each around 6% and MIM components around 1%. Total European PM Production in 2014 by value was estimated to be €10.2 billion (Fig. 5). The powder shipments stood at about 170,000 tonnes for ferrous and at about 25,000 tonnes for non-ferrous powders. MIM component sales had grown to about €275 million in 2014. Hard materials production slightly decreased to about 14,000 tonnes in 2014. The number of Additive Manufacturing machines sold increased by 55% to about 550 in 2014, stated Molins.

According to Molins, the technology goals and trends in Europe are likely to be:

- A strong co-operative push to prove PM as a viable technology for main gearbox gears
- Development of surface densification as a fatigue improvement technology
- VVT applications in growing demand require sophisticated machining, including green machining and very tight tolerances.
- New lubricants capable of lubricating at reduced addition levels to reach higher compacting densities
- Increasing electrification of vehicles seems to call for new soft magnetic applications, but the scope is still unclear.
- Developments in bi-metal, high-performance bushings

Memorial lectures focus on Additive Manufacturing, green technology and OEMs

P R Roy Memorial Lecture

Dr G K Dey, of Bhabha Atomic Research Centre (BARC), gave this year's P R Roy Memorial Lecture entitled 'Fabrication of net shapes by combustion synthesis and by using lasers'. During the presentation, Dr Dey discussed the prominent features of two rapid net shape forming processes, namely combustion synthesis, also known as self-propagating high temperature synthesis (SHS), and Laser Engineered Net Shaping (LENS).

Combustion synthesis, as a means of materials processing, has several unique and attractive attributes, such as self-generation of energy, high reaction temperatures (1500 to 4000°C), short processing times (a few seconds to a few minutes), high temperature gradients and high heating and cooling rates. Many intermetallic compounds, particularly the aluminides of nickel and titanium, can be readily synthesised by the process because of their high adiabatic temperatures and high heats of mixing. The combustion synthesis of several intermetallic compounds, the effect of processing parameters on the microstructures and the mechanism of synthesis in the case of NiAl, Ti and NiTi were discussed.

Laser Engineered Net shaping is an Additive Manufacturing technology for fabrication of three-dimensional metallic parts directly from computer aided design (CAD) solid models. Metal parts are fabricated by injecting the metallic powder directly into the melt pool, created using a high power laser beam. Each layer of the object is fabricated by moving the X-Y table

Fig. 6 Dr G K Dey, Bhabha Atomic Research Centre, presented the P R Roy Memorial Lecture

Fig. 7 David Prakash and Paresh Turakhia of Mahindra & Mahindra, receiving their plaque for presenting the Tamahankar Memorial Lecture from Narsi Chandrachud

Fig. 8 V Hariharan of Tata Motors Ltd receiving his plaque from Aniket Gore for delivering the S L N Acharyulu Memorial Lecture

or laser head. After completing each layer, the head is moved up vertically and the whole part is fabricated, layer by layer. Inert shroud gas is often used to shield the melt pool from oxidation through atmospheric oxygen for improved properties of the part formed.

LENS is similar to Selective Laser Sintering (SLS) in its basic approach of making solid components by a layer additive method. Unlike selective laser sintering however, the metal powder is added directly while making the component. In SLS, a laser is used to selectively fuse the preplaced powder, a new layer of material is applied on top and the process repeated until the part is completed. The main goal of these layered manufacturing technologies is to produce fully dense and net shaped metal parts in a single step without special tooling involved, in order to minimise cost and time, stated Dr Dey.

Tamahankar Memorial Lecture

The Tamahankar Memorial Lecture, entitled 'Alternative Thinking - Adopting Green Technology in Automobiles', was this year delivered by David Prakash and Paresh Turakhia of Mahindra & Mahindra Ltd.

With stringent emission limits for automobiles being imposed, a major challenge for this sector is to improve the performance of automobiles whilst adopting green technologies, stated Prakash. At Mahindra, there is a continuous effort to improve fuel efficiency. Under the company's RISE philosophy, advocating an alternative thinking approach, the fundamentals of automotive design are challenged and changed to shape the future.

Among the various initiatives undertaken is the use of sintered parts. Seen as a green process, Powder Metallurgy is helping to address the product demands, such as improved fuel economy, without reducing performance. PM offers lightweight components and reduces wastage. Adopting such technologies, Mahindra & Mahindra have shown their commitment to being a responsible social corporate and creating a value offering to all stakeholders, the authors stated.

S L N Acharyulu Memorial Lecture

The S L N Acharyulu Memorial Lecture was presented by V Hariharan and Deodatta Shende of Tata Motors Ltd., Pune, entitled 'Unexplored Scope of Powder Metallurgy - an Auto OEM's Viewpoint' (Fig. 8).

Fellow of PMAI Awards

A number of Fellow of PMAI awards were presented to distinguished individuals who have contributed to the Powder Metallurgy industry. The ceremony began with a posthumous Fellow of PMAI award announced for the late Kempton H Roll. Prof Ramakrishnan spoke of Roll's achievements and received the award on his behalf. Dayasagar Mrig, ex-GKN, received the FPMAI award for his contribution towards the development of compaction presses (Fig. 9) and Dr Vijay N Vaidya received the FPMAI award for his contribution towards production of ultrafine and nano powders and dental ceramics (Fig. 10).

Fig. 9 Dayasagar Mrig received the FPMAI award from V Srinivasan of Höganäs

Fig. 10 Dr Vijay N Vaidya had receiving FPMAI award from V Srinivasan of Höganäs

Fig. 11 Masanori Kikuchi, President of Porite Corp, opened the PM-16 exhibition

Fig. 13 The PM-16 exhibition included representatives from national and international companies

Fig. 12 Lunch and refreshment breaks were located in the main exhibition hall

Fig. 14 Some 19 companies from India, China, Germany, Sweden, Switzerland, Italy and UK exhibited at PM-16

Amongst the various automotive parts manufacturing processes, Powder Metallurgy technology is in a unique position as it has the potential to produce parts with varied material and property combinations, the authors stated,.

The PM industry, during the past few decades, has grown largely on the basis of the cost savings associated with near-net shape processing compared to other metalworking methods. A very high degree of raw material utilisation and relatively low energy requirement per kg of finished part are key attractions, added Hariharan. In some cases, the conversion of a cast or wrought component to Powder Metallurgy provides cost savings of over 40%, a figure that is clearly moving auto OEMs towards the PM industry.

Hariharan stated that this presentation was an attempt to share a few light weighting concepts with the audience. It endeavoured to focus on the expectations of the auto OEMs regarding new developments, such as the use of PM bushes for leaf springs / axle beams, PM coatings to eliminate carburising, cost effective brake pad liners to be compatible with conventional and composite brake drums / disc brakes and use of alternative process to forging for differential gears, clutch hubs, planetary gears to name a few.

Exhibition highlights applications of PM in the automotive and engineering industries

The PM-16 exhibition was opened by Masanori Kikuchi, President of Porite, during a traditional ribbon cutting ceremony (Fig. 11). The exhibition included an international mix of companies based in India, China, Germany, Sweden, Switzerland, Italy and United Kingdom.

In total 19 companies were represented and those exhibiting included Codina Metallic Pvt. Ltd., Dorst Technologies, Fluidtherm, Hoeganaes Corporation, Höganäs, IMERYS Graphite and Carbon, Innomet Powders, Makin Metal powders (UK) Ltd., Newmet Pvt. Ltd., Osterwalder AG, PMAI, Pometon India Pvt. Ltd., PVA Industrial Vacuum Systems GmbH, Rio Tinto Metal Powders, SACMI IMOLA S. C, Sharda Enterprises, Singhal Sintered Pvt.Ltd., SLM Metals Pvt. Ltd., SMS Group GmbH, Speciality Sintered Products, UNIMARK and Yangzhou Haili Precision Machinery Manufacturing Co. Ltd.

Conference presentations demonstrate range of PM technology

The conference included over 100 presentations with a number of special interest sessions that showcased the latest in Powder Metallurgy technology. The following represent

Category	Percent of total AM made products	Shipments of US made AM Products ($millions, 2011)*	Total Shipments ($millions, 2011)	AM Share of Industry Shipments
Motor vehicles	19.5%	48.0	445,289.4	0.01%
Aerospace	12.1%	29.8	157,700.7	0.02%
Industrial/business machines	10.8%	26.6	365,734.8	0.01%
Medical/dental	15.1%	37.2	89,519.5	0.04%
Government/military	6.0%	14.8	32,784.4	0.05%
Architectural	3.0%	7.4	72,186.9	0.01%
Consumer products/ electronics, academic institutions, and other	33.6%	82.7	895,709.8	0.01%
TOTAL	**100%**	**246.1**	**2,058,925.5**	**0.01%**

*Table 1 Additive manufactured goods shipped in 2011 *These value calculations assume that % of each AM product is the same for US and globally. It is also assumed that the share of AM systems sold is equal to share of revenue for AM products*

a small selection of the conference presentations made at PM-16, but demonstrate the wide range of topics covered during the event.

Additive Manufacturing of automotive parts

The Plenary Session began with a presentation entitled 'Additive Manufacturing for Making Fully Dense Automotive Parts' given by S R Sundaram, Technical Advisor - Powder Metal Division, Pricol Ltd. In 2013, stated Sundaram, additive manufactured goods globally accounted for an estimated $967 million and, of these, the US accounted for 38% of global production. To demonstrate the relative size of the AM industry, Table 1 shows that the goods produced using Additive Manufacturing methods in the US represent between 0.01 % and 0.05 % of their relevant industry subsectors. Sundaram went on to discuss the various cost factors involved in AM produced parts and the possibility of applying AM technology in PM part production.

Additive Manufacturing has become a significant technology, stated Sundaram, and is no longer considered just a prototyping technique. Currently, AM technologies are targeting parts for aerospace or medical implants, but there are opportunities for use in the automotive sector. As well as being used for complicated parts, AM can be used to make complete assemblies, for example, thereby shortening supply chains and reducing inherent costs and production time.

There are some parts, added Sundaram, such as helical gears, two-wheeler connecting rods and two-wheeler transmission gears, which are manufactured with expensive and time consuming processes. Perhaps consideration can be given to producing these parts by Additive Manufacturing, suggested Sundaram.

Additive Manufacturing of magnesium alloy powders

Dr Deepak Madan of Magnesium Elektron Powders, New Jersey, USA, discussed the laser Additive Manufacturing of magnesium alloy powders in a paper co-authored by Rajiv Tandon.

A spherical gas-atomised Elektron® MAP+43 powder with nominal size of D10=50 µm, D50=83 µm, D90=133 µm, and nominal composition of Mg-4%Y-3%Nd-0.5Zr was used for the Directed Energy Deposition (DED) study. A powder with a nominal particle size of D10= 8.4 µm, D50=23.5 µm, D90=42 µm of the same alloy was used for the laser powder bed investigation.

The DED study indicated grain coarsening due to re-melting and solidification of powder. A high as-deposited density (>99%) could be achieved, stated Madan. Micro-hardness of the deposited layer ranged from 76 to 81 HVN and residual porosity was eliminated via HIPing. As-deposited material exhibited yield strength of 143 MPa, UTS of 195 MPa and ductility of 3.8%. HIPing

resulted in a yield strength of 142 MPa, UTS of 213 MPa and ductility of 6.8%. The T5 heat-treatment did not change the properties of either as-deposited or HIPed samples. However, the T6 treatment improved yield, UTS and elongation. The HIPed and T6 treated samples showed a yield strength of 167 MPa, UTS of 255 MPa and ductility of 7.9%, which compares very favourably with as-cast WE43B (which, in a T6 condition, has a typical yield strength of 180 MPa, UTS of 250 MPa and ductility of 6%).

For the Laser Powder Bed method, a combination of high laser power (70-100W), slow scan speed (200-750 mm/s) and a hatch spacing between 30 and 70 µm resulted in a density of 90% of theoretical. The powder initially used in this study had a D10=8.4 µm and had significant level of super-fines below 10-15 µm, which effected flowability, leading to non-uniform spreading and higher porosity. Additional trials using a slightly coarser powder, with a D10=23.5 µm and minimal super-fines, showed improved flowability and increased the build density to >98% of theoretical.

The author claimed that the laser powder bed study showed promising results with Elektron® MAP+43 powder and further optimisation work is being conducted using narrower size distribution powders of both Elektron® 43 and Elektron® 21 alloys.

The DED process can be used to build simple shapes using magnesium alloy powders. The parameters and methodology developed in this study can be used as a platform to develop protocols for scaling up. A high laser power (1750-2250 W) was necessary to achieve good quality deposits with densities exceeding 99%. The resulting mechanical properties of the as-deposited Elektron® MAP+43 showed yield strength of 170 MPa, UTS of 250 MPa and elongation of 6.5%, which compares very favourably with as-cast WE43B (in a T-6 condition), stated Madan.

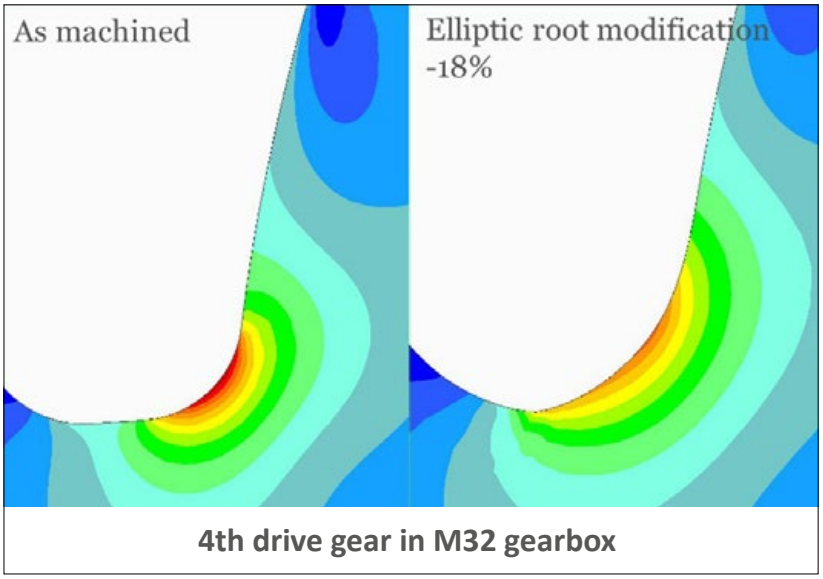


Fig. 15 Illustration of tooth root optimisation for stress reduction in a PM gear for a six speed automotive gearbox

Improving the machinability of PM steels

In the second Plenary Session at PM-16, Roland T Warzel III and Bo Hu of North American Höganäs presented a paper on improving the machinability of PM steels. Complex Powder Metallurgy parts can require machining operations to add features not possible through compaction, to meet final tolerances or to provide a required surface finish. Improving this process can often be a challenging task due to the number of variables which can affect the final machinability. Use of machinability enhancing additives is therefore an easy and common way to improve machinability of PM materials.

In the presentation, different material systems and additives were compared for machinability in laboratory and production conditions. Large improvements in tool life were observed for the advanced materials and additives which improved productivity.

Fatigue considerations for Powder Metallurgy components

Thomas Schmidtseifer, Michael Andersson and Anders Flodin of Höganäs AB, Sweden, presented a paper, 'Design for fatigue with PM', that highlighted important aspects of the Powder Metallurgy process to consider when designing components.

When a PM component is converted from, for instance, machined steel by just copying the existing design, the result will be sub-standard, stated the authors. By properly designing for PM from the beginning, several advantages, for instance weight reduction and lower stresses in critical areas, can be achieved, contributing to both better and more robust PM solutions. This also extends the application areas for PM to new, more demanding components.

Properly designing for fatigue is important in order to reach the optimal strength of a part. Fatigue strength is influenced by many different factors, such as selecting the right material and process combination, heat treatment and so on. However, in many cases, the strength of a component can also be greatly improved by smart design modifications, such as reducing or removing stress concentrations. Often small modifications can be introduced that will decrease stresses. Fig. 15 shows an example of a tooth root optimisation for stress reduction in a gear for a six speed automotive gearbox, where the PM solution showed 18% lower stresses compared to the machined solution.

The paper demonstrated how design modifications can be introduced to make a more robust fatigue design when converting components to PM manufacturing. Examples were given for applications such as gears and connecting rods. For instance, consideration was given to how the tooth root of a gear can be redesigned, or the stem of a connecting rod, to reduce the stresses in the component.

The importance of suitable fatigue data was exemplified by showing how full SN-curves can be used to determine the service life of a part under load spectra and what design modifications translate into in terms of fatigue life. It was also shown how suitable fatigue models can be applied to stress concentrations to make sure that the material is optimally used.

Dimensional control in Powder Metallurgy components

Powder Metallurgy is a net shape process and hence an understanding of what controls dimensional change is important. In the presentation by Fran Hanejko, Bruce Lindsley of Hoeganaes Corporation, USA, Kalathur S Narasimhan of P2P Technologies, USA, and Mahesh Kamble of Speciality Sintered, India, factors affecting dimensional control in PM parts were discussed.

Alloying elements such as C, Mo, Ni, Mn, Cr and Cu increase the hardenability of steel, stated the authors. Further, the amount of pre-alloyed elements in the base iron affects the transformation products found after sintering. The cooling rate, pre-alloyed elements and admixed additions determine the final microstructure, dimensional change and mechanical properties in the sintered compact.

Four premixes were prepared as shown in Table 2. The mixes containing atomised Acrawax C were conventional premixes prepared via double cone blending. The premixes containing the warm die lubricant (AncorMax 200™) were prepared via a proprietary premixing process. These premixes were utilised to evaluate the dimensional change variability during the heat-treat response of a prototype gear. The gear geometry used is shown in Fig 16. Approximately 1,000 gears were made from each premix,

The authors reviewed the benefit of using a 0.3 prealloyed Mo grade powder with FC-0208 type of powder both in as sintered and heat treated condition. For heat treated parts the use 0.3%Mo without Cu was found to give a better dimensional precision than FC-0208.

FC-0208 parts, made with the Ancorbonded binder/lubricant approach used in making higher density AncorMax 225 powder, provides a tighter dimensional tolerance by ensuring all the graphite goes in to alloying compared with a non- bonded mix. It was found, that in the case of higher performance sinter-hardenable grades, Ancorsteel 4300 provided good dimensional precision.

Characterisation of iron powder mixes

Prakash Khole, Chantal Labrecque, Maryam Moravej and Ian Bailon-Poujol, of Rio Tinto Metal Powders, discussed the characterisation of iron powder mixes prepared with a compressible iron powder.

Atomet 31 is a compressible iron powder that is produced via iron granulation, grinding and decarburisation. This product was specifically developed for the Indian market and is suitable for applications requiring good compressibility and high green strength, such as bearing parts, pulleys, oil pump parts and valve guides.

The paper gave details of this product from its production step to the final properties obtained in Fe-C and Fe-Cu-C mixes as per MPIF Standards F-0005, F-0008, FC-0205 and FC-0208. The effects of different types of additives (Cu, graphite) on the sintered properties were evaluated. Finally, an FC-0208 formulation with 0.45% Fe3P was included in the study in order to assess the addition's specific effect on the mechanical properties. Microstructures and apparent hardness obtained under various conditions were compared to those achieved with a reference steel powder.

Mix	Base Iron	% Copper	% Graphite	% Lube & Type
1	Unalloyed iron powder	2	0.8	0.75% Acrawax
2	Unalloyed iron powder	2	0.8	0.4% warm die lubricant
3	Prealloyed 0.3% Molybdenum			
NA	0.8	0.75% Acrawax		
4	Prealloyed 0.3% Molybdenum		0.8	0.4% warm die lubricant

Table 2 Composition of premixes

Fig. 16 Spur gear produced to evaluate part-to-part consistency in the heat-treated condition

Award winning components

A flyweight assembly manufactured by Pricol, received the Best PM Part award from the PMAI. The complex component is part of a diesel fuel injection pump and consists of a flyweight carrier, cylindrical gear and bi-metal bush. Made from three different materials, the part involves joining two parts of dissimilar chemistry by projection welding (Fig. 17). The parts are heat treated to achieve the required properties specified by the customer.

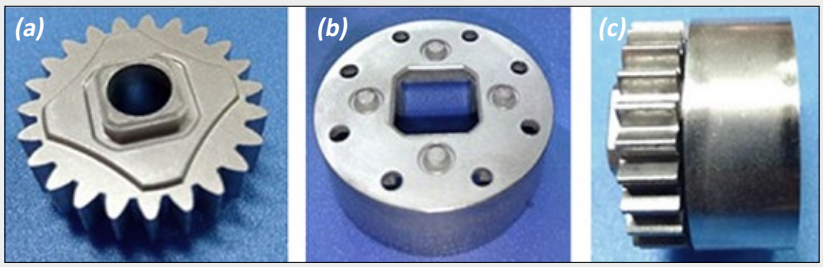


Fig. 17 The flyweight assembly involves joining the two parts, (a) and (b), by projection welding. The joined component is shown in (c)

A Certificate of Excellence was presented to GKN Sinter Metals for a hub component used in an automotive transmission clutch assembly.

A further Certificate of Excellence was presented to Speciality Sintered Products Pvt Ltd for an annulus assembly for use in starter motors.

The influence of copper powder features

The influence of copper powder features on the performance of copper-based sintered components was discussed by I. Rampin, F Bortolotti, M Zanon and A Breda of Pometon Powder S.p.A., Italy.

Copper and copper alloy powders are used in several industrial applications, the prominent one being in electric and electronic industries due to their excellent electrical and thermal conductivities, stated Rampin. The most common copper powder production processes, such as atomisation and electrolysis, obtain the required shape and size distribution through control of process parameters. These characteristics affect the performance of copper based sintered components.

The influence of different copper powder types and process properties such as compaction pressure, dimensional change, final sinter density and electrical conductivity were discussed and guidelines for optimal powder selection recommended.

High density solutions and efficient lubricants

There are a number of possible routes for achieving higher density in PM components, such as high temperature sintering, copper infiltration, liquid phase sintering and double pressing. It is, however, attractive if high density can be achieved by the single press and single sintering process, thus avoiding large shrinkage during sintering in order to keep close tolerances.

Paul Skoglund of Höganäs AB, Sweden, gave a presentation entitled 'High density compaction solutions, efficient lubricants'. Recent developments with more efficient lubricants and powder mixing concepts open up new possibilities to produce PM components to high density in a cost efficient way. The possibilities of combining high performance lubricants with best practice compaction procedures were discussed.

Powder Metallurgy transmission quill gears

Transmission quill gears are traditionally hot forged steel parts, often used in constant mesh manual transmissions. G Magendran of Mahindra & Mahindra Ltd., Pune, presented the latest developments in manufacturing these interesting components via the Powder Metallurgy route.

The quill gear allows a drive shaft to shift its position relative to its driving shaft either axially, radially or both. It has external teeth which are positively engaged with the intermediate gear and sleeve, which permits the required motion to the drive shaft. Quill gears directly engage with shift gears on the outer surface and bearings on the inner surface. They need to have high strength and durability. These properties can be improved by carburisation heat treatment. However, in their existing design, such processes can lead to increased costs.

Mahindra & Mahindra Ltd has developed quill gears through a Powder Metallurgy process. The technique involves rapid cooling in the furnace to generate high strength and wear properties, using optimised material composition and sintering conditions. Success is achieved in the development of quill gears via sinter hardening, avoiding the use of forging and a second hardening process. This presentation discussed material composition, the sinter hardening process, a comparison of mechanical and metallurgical properties and validation of the results.

Properties of MIM 440C made by pre-alloy and master alloy routes

Martin A Kearns, Mary-Kate Johnston, Keith Murray and Paul A Davies of Sandvik Osprey Ltd., UK, Viacheslav Ryabinin and Erainy Gonzalez of TCK S.A., Dominican Republic presented a paper entitled 'Studies on the Effects of Nb on Sintering and Properties of MIM 440C made by Pre-alloy and Master Alloy Routes'.

According to Paul Davies, one of the most versatile alloys in use in Metal Injection Moulding is 440C martensitic stainless steel, which offers high hardness and good corrosion resistance. This combination is

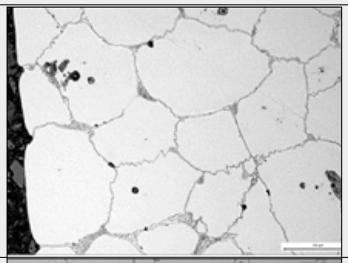
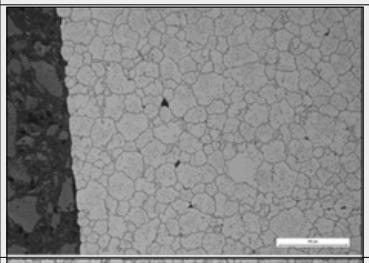
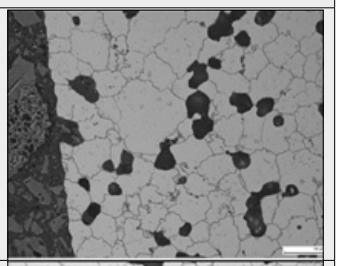
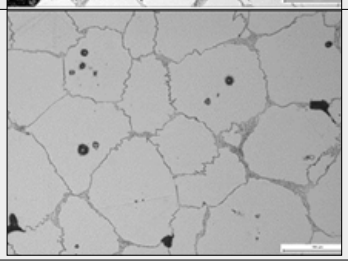
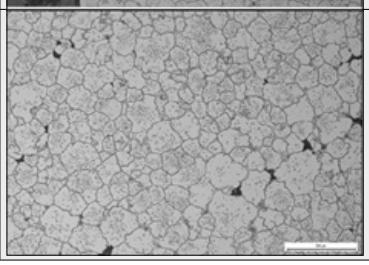
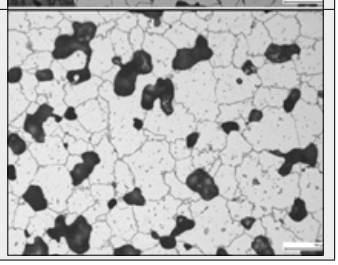
Lot #	121014-1 (440C)	121114-1 (440C(Nb))	121214-1 (440C(Nb) MA)
Density %	99.4	99.2	93.3
Final %C	1.06	1.21	1.09
Hv10 hardness	310	413	244
Surface 500x Micron bar = 500µm			
Centre 500x Micron bar = 500µm			

Fig. 18 Microstructures of different alloy variants after sintering at 1260°C

suited to service in automotive fuel injector parts, medical pliers and a range of tool parts, for example in textile machinery. Achieving reproducible properties and consistent hardness requires close control of carbon levels, in particular.

There are a number of variants on 440C in use today, some with enhanced carbon levels to achieve higher hardness and some with additions of Nb which are claimed to increase the sintering process window for the alloy. The study showed that sintering 440C in nitrogen at 1240-1260°C is effective in achieving virtually full part density for 80%-22 µm PA powders with and without Nb present (Fig. 18) and that the sintering temperature required for full density is dependent on the balance of C and Nb in the alloy. Higher temperatures are needed to obtain full density in parts made via a master alloy route: A 90%-22 µm grade enables full densification at 1280°C while the 80%-22 µm grade reaches 97% density at this temperature. The densification behaviour can be rationalised with reference to Thermocalc studies.

While achieving peak density is desirable, it was stated that this may be at the cost of enlarged grain size and lower final hardness levels. Niobium is helpful in restricting grain growth and maintaining hardness levels. Carbon loss during the sintering process is predictable for gas atomised powders with and without blended carbonyl iron powder and is dependent only on the amount of oxygen present in the starting powder and not apparently on the sintering temperature in the normal sintering range 1240-1280°C.

In common with previous studies on other master alloy systems it was stated that part distortion appears more pronounced in parts made with pre-alloyed powders compared with master alloy powders. This may be one reason to adopt a MA route albeit a higher sintering temperature will be needed to achieve full density.

The author concluded that gas atomised 440C pre-allloy and master alloy powders are both ideally suited to producing high performance components to close tolerances with excellent control of carbon leading to uniform shrinkage and predictable properties.

Soft magnetic composites for automotive applications

K Malobika, B Aviral, H Y Neha, C Dibyendu, Ch Raju Satyanarayana, V Chandrasekaran and R Gopalan of International Advanced Research Centre for Powder Metallurgy and New Materials (ARCI) and Research Centre Imarat (RCI) in Hyderabad, presented a paper discussing the promises and challenges of soft magnetic composites for automotive applications.

Soft magnetic materials (SMM) for automotive applications demand high magnetic induction, high permeability and low core losses at the operating frequencies. These can be achieved by selecting or designing materials with high magnetisation 'Bs', low coercivity 'Hc' and increased electrical resistivity 'ρ' to effectively reduce the eddy current losses.

Fe-based soft magnetic materials are useful for low to moderate frequency applications with phosphorus, aluminium and silicon as the usual alloying elements. For high frequency applications (>1 kHz), ferrites are the most popular materials. However, ferrites have drawbacks of having relatively low values of magnetic induction 'Bs' and

permeability 'μ'as compared to those in Fe-based soft magnetic alloys, the authors stated.

Soft magnetic composites (SMCs) are typically iron or iron based alloys having an insulation film of either organic or inorganic coating on the surface developed through either milling or solution techniques for automotive applications, wherein the operating frequencies are > 1kHz. PM processing provides flexibility in either alloying or additions of non-magnetic materials to the base systems so as to alter the electrical and magnetic properties. PM based SMCs are amenable for the minimising of the magnetic anisotropy normally present in conventional laminated sheet metal technology of silicon steels.

The unique properties of SMC include isotropic behaviour for three-dimensional flux distribution, relatively low core loss at medium and high frequencies, improved thermal characteristics, flexible machine design and 3D design solutions. The evolution and evaluation of these SMC systems, with emphasis on automotive applications, were presented in this talk.

At ARCI, an R&D programme has been initiated with the aim of obtaining an electrically insulating layer on the iron powder and further hot consolidation using conventional as well as spark plasma sintering. Typically, magnetic induction 'Bs' of 1.5-1.6 T, coercivity values of 'Hc'<2 Oe with permeability 'μ' >4000 were achieved in samples with relative densities of ~ 96%. The studies on SMCs, with their microstructural features and magnetic property measurements, were highlighted.

Enhanced processing developments in steel powders

Bruce Lindsley, Fran Hanejko and Cecilia Borgonovo of Hoeganaes Corporation, USA, submitted a paper focused on enhanced processing developments in steel powders. The paper was presented by Narsi Chandrachud and discussed how warm die compaction with AncorMax 225 binder/lubricant enables green and sintered densities in excess of 7.4 g/cm³ at compaction pressures of approximately 750 MPa.

While the PM process produces net or near-net shape components, many parts are machined to deliver high precision features, cross holes, transverse grooves, etc, the author stated. It is estimated that 40-50% of PM steels require additional machining in applications where wrought steels are normally employed. Components with poor machinability result in higher insert costs, reduced capital utilisation and unpredicted downtime.

One of the advantages of PM is that machinability enhancers can be incorporated into the powder prior to compaction. Engineered powders with enhanced attributes are an important tool for developing new parts and improving current applications. A newly introduced machining enhancer, AncorCut, was found to improve machinability of a variety of alloy systems and microstructures, stated Chandrachud. This benefit in machinability was observed with both turning and drilling of several different alloy systems (Fig. 19).

The new additive also avoids the accelerated corrosion (rusting) found in sintered PM parts containing MnS and provides stable machining characteristics. Chandrachud discussed how this new advanced premixing technology is currently being utilised in the production of high density automotive and non-automotive ferrous components, providing parts producers another tool to improve the manufacturing and cost competitiveness of PM components.

Innovative Hot Isostatic Pressing methods

Dr G Appa Rao of Defence Metallurgical Research Laboratory (DMRL), Hyderabad, discussed innovative Hot Isostatic Pressing methods and identified the development of critical components using this process. Hot Isostatic Pressing (HIP) involves simultaneous application of inert gas pressures up to 200 MPa and high temperatures up to 2000°C. HIP processed materials and objects exhibit near 100% theoretical density and isotropic properties with large sizes and near net shapes.

Applications such as consolidation of a wide variety of particulate materials into near net shaped components, diffusion-bonding of similar/dissimilar materials and defect-healing of investment cast components were discussed. The chemical composition, purity levels, physical characteristics and phase structure of powders as well as the encapsulation materials, together with HIPing cycle parameters, greatly influence the performance of the

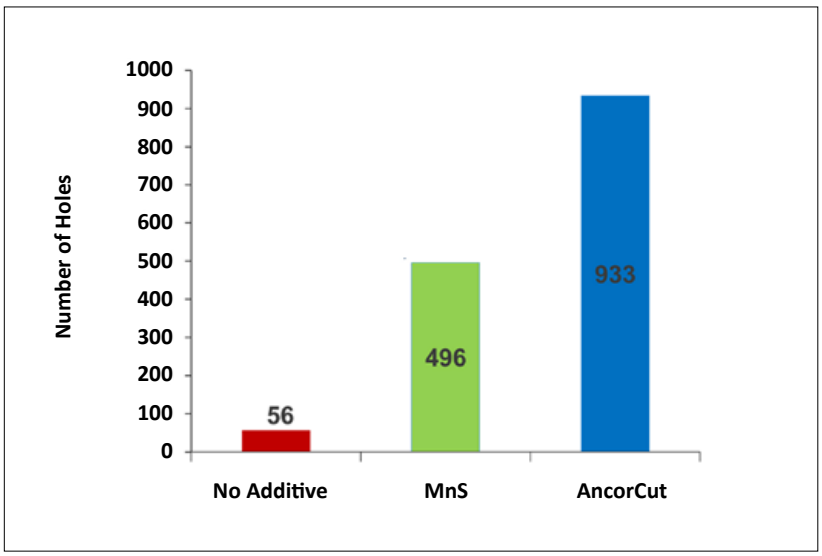


Fig. 19 Carbide drill life in FD-0405 with no additive, MnS and AncorCut at 3500 rpm and 508 mm/min feed

HIPed products to meet the specific requirements, stated Dr Rao. The strategies and innovative approaches adopted in the development of HIPed products for various applications were discussed.

Particulate materials in diesel pollution control

Powder Metallurgy and particulate materials, by being a green technology, offers a variety of solutions to combat pollution effects by way of offering unique electrodes, materials for incinerators, nano and activated catalysts, porous membranes, filters, foams and honeycombs as catalyst supports.

Dr T R Rama Mohan, Consultant in Powder Metallurgy, Ceramics and Diamonds, presented a paper on the use of particulate materials in diesel pollution control. This paper focused on metallic and ceramic honey combs as catalyst supports and particulate filters used in automobiles, in particular diesel-engined vehicles.

Novel sintering of diamond tool matrices

Diamond Tools are particulate composites, in which, predominantly, synthetic single crystal diamonds are dispersed or impregnated in a metallic or ceramic/ inorganic or thermoset polymer matrix. Each protruded point of the single crystal diamonds present in the composite acts as a single point tool. Dr Murli Gopal Krishnamurthy, Consultant, Novoken Innovations, Mumbai, presented a paper discussing the 'free' sintering of diamond tool matrices.

Deterioration of diamond occurs due to heating to high temperatures. In the presence of metallic elements, catalytic graphitisation occurs. Thus, the basic requirement of any consolidation technique is to limit the maximum processing temperatures to much less than 1000ºC, so that the cutting properties of diamonds are not greatly affected. To date, Direct Hot Pressing is the most preferred consolidation technique for the manufacturing of metal-matrix diamond tools. The processing temperatures and pressures are in the range of 750-950ºC and 25-50 MPa, respectively, in high density, high conductivity graphite moulds with rapid heating cycles. The classical matrix has been cobalt, especially made from ultrafine powders.

"There is a need for cost effective, ultrafine powders sinterable at less than 950ºC, with good pore free density and tailorable wear resistance and toughness"

To modify the matrix-diamond interface, mechanical properties, wear characteristics and to reduce cost, various additives are included such as iron, nickel, copper, tungsten, sintered cobalt-cemented tungsten carbide (WC-Co), plain tungsten carbide (WC), fused tungsten carbide (W_2C), Misch metal powders, yittrium Oxide (Y_2O_3) etc. Hot pressing times are in the range of three minutes at temperature. Matrices are formulated based on cobalt-, iron-, nickel- and copper-based compositions.

Hot pressing is the rate limiting process in the production of diamond tools. The capital cost of hot presses and power requirements due to multiple installations and to cope with production requirements make it a very complicated operation. Moreover, the use of expensive graphite moulds is prone to oxidation, wear, breakages and the like. They also add greatly to the cost of production. Expanding applications and the need for smaller tool bits make it uneconomical for hot pressing to be sustained as a major manufacturing process.

"Free" sintering or pressure-less sintering of diamond tools in a batch or continuous furnace with controlled reducing atmosphere is a viable option, stated Krishnamurthy, though fraught with operational and technological challenges. Most of the diamond tool manufacturing level is small due to the high cost of raw materials, complicated processes, expensive machinery, large number of required formulations and types of tools and business cycles.

The switch over to pressure-less sintering also throws up challenges in the choice of materials for the matrices. There is a need for cost effective, ultrafine powders sinterable at less than 950ºC, with good pore free density and tailorable wear resistance and toughness, joinable by diffusion bonding/ brazing/ welding, and secondary operations as the need demands. Some of these aspects were discussed.

New lubrication systems for improved performance

Shock absorber parts such as pistons, cylinder ends and rod guides are multi-level parts with rather complex geometry. These are often produced by means of PM due to the net shape and design freedom the process offers, in combination with the dimensional precision that is a critical requirement. Mahesh Nipanikar of Höganäs India Pvt. Ltd, Pune, discussed new lubrication systems that offer improved performance in powder mixes suited to the production of these parts.

The relatively low density, in combination with the complex geometries and the demand for dimensional accuracy, make the sponge iron powders a natural choice for the shock absorber parts. The new lubricant and mix system, developed by Höganäs, further improves dimensional stability and, in particular, green strength. This system, Intralube S, is tailored to work with sponge powders at low densities. It is a Zn-free and environmentally friendly system. The optimal operating conditions and achievable properties of the lubricant system were discussed.

Awards recognise significant work in Powder Metallurgy research and development

This year's event included a number of awards for students and researchers aimed at rewarding outstanding research work presented at PM-16. An expert committee evaluated the submissions and the awards were presented during the conference.

Grand Student Award

The winner of the Grand Student Award was announced as Prakash Mohan, PhD Scholar at the University Polytechnic of Valencia, Spain. In this award winning paper, co-authored by Angelica Amigo Mata and Vicente Amigo Borrais, Institute of Materials Technology (ITM-UPV) University Polytechnic of Valencia, Spain, Mohan discussed the effects of Fe and Mo content on the microstructure and mechanical properties of Ti-Mo based alloys prepared by elemental blend and mechanical alloying techniques.

Titanium and its alloys are commonly used biomaterials due to unique properties such as high corrosion resistance, low elastic modulus, high mechanical strength to density ratio and good biocompatibility, stated Mohan. Ti β alloys based on the Ti-Mo alloy system offer much interest to biomaterials researchers. The addition of Zr and small amounts of Fe improves the β-phase stability, improving the properties of Ti-Mo alloy. These alloys can be produced by Powder Metallurgy using Elemental Blend (EB) techniques (600 MPa compaction pressure) and Mechanical Alloying (MA) techniques at 600 and 900 MPa compaction pressure (Fig. 20).

The paper described the microstructural characterisation obtained by SEM and physical and mechanical properties obtained by bending tests, Archimedes tests and ultrasonic tests of Ti-Mo-Zr-Fe alloys made by EB and MA. Mechanical properties and microstructures of these powder mixing processes was compared. The addition of small amounts of Fe further increased β-phase stability, improving the properties of Ti–15Mo–6Zr–xFe alloy, stated Mohan.

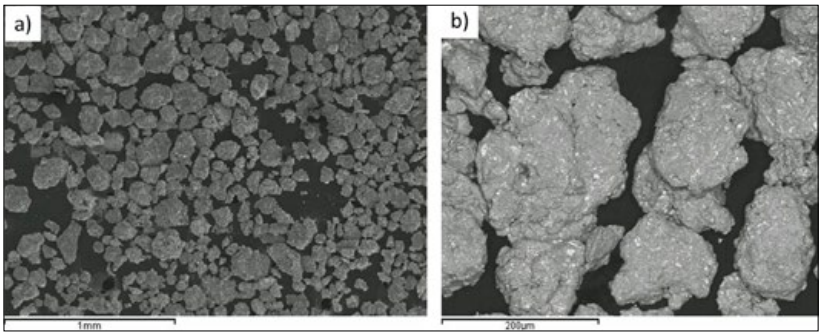


Fig. 20 SEM images of Ti12Mo6Zr2Fe powder by mechanical alloying method for 45 min (a) general aspect of the powder, secondary image (b) detail of the powder, back-scattered image

Guiding Hand Faculty Award

This award is presented to the principal lecturer of the winner of the Grand Student Award. As Mohan's lecturer, Dr Vicente Amigo Borras, University Polytechnic of Valencia, Spain, received the prize.

Young Professional Award

A Young Professional Award was presented to Dr Kaustubh Kambale, Assistant Professor, Department of Metallurgy and Materials Science, College of Engineering, Pune. In the paper co-authored by Ajit Kulkarni and Narayanan Venkataramani, Department of Metallurgical Engineering and Materials Science, Indian Institute of Technology, Bombay (IITB), Kambale identified the effect of nano sized starting materials on the dielectric and ferroelectric behaviour of barium titanate.

Barium titanate is a ceramic widely used in the electronic industry due to its high dielectric constant and low tangent losses. Barium titanate used in electronic circuits is not in powder form but as a sintered product with shape formed as per the component design. Thus, it becomes important to study sintering characteristics of barium titanate. The main objective of the research work was to synthesize barium titanate from micron sized barium carbonate and titanium oxide having different particle size (0.7 µm, 50-60 nm and 80-90 nm) and study the effect of particle size of starting materials on sintering characteristics and dielectric and ferroelectric properties of barium titanate.

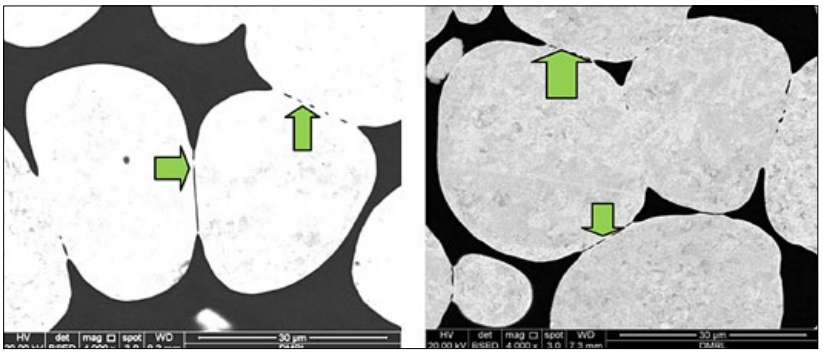


Fig. 21 Back scattered electron micrograph of tungsten heavy alloy after three cycles of heat treatment showing penetration of the matrix phase (shown by arrow)

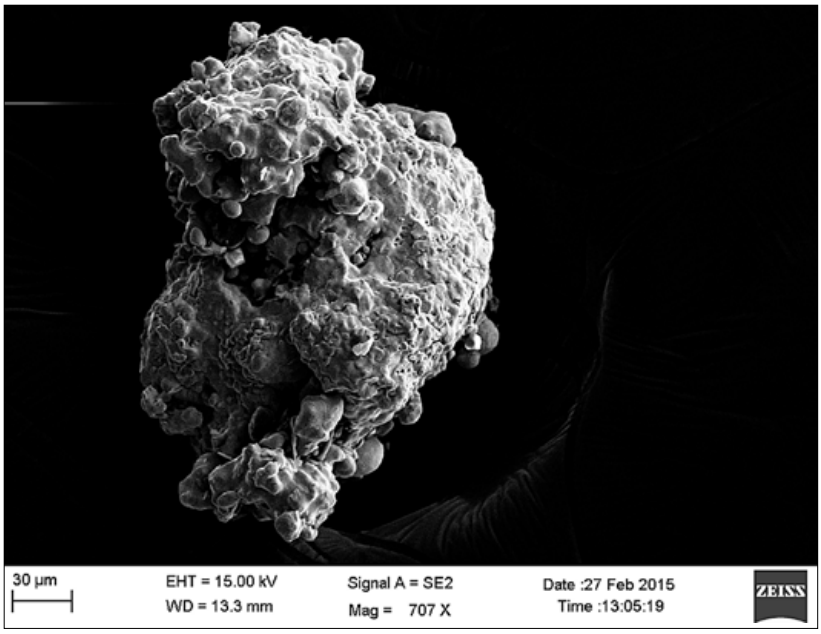


Fig. 22 SEM image of Astaloy 0.85% Mo+0.3%C+1 % Zn stearate powder

Young Professional Award

A further Young Professional Award was presented to U Ravi Kiran, Defence Metallurgical Research Laboratory, Hyderabad. The paper, co-authored by Sankara Narayana and T K Nandy, Defence Metallurgical Research Laboratory and G V S Nageswara Rao, National Institute of Technology, Warangal, focused on the effect of cyclic heat treatment and swaging on mechanical properties of cobalt and molybdenum containing tungsten heavy alloys.

Tungsten heavy alloys (WHA), prepared by liquid-phase sintering, are composite materials in which quasi-spherical shaped hard bcc particles are embedded in the ductile Ni–Fe–W solid solution fcc matrix. Tungsten heavy alloys offer a unique combination of properties such as high density (16–18 g/cm^3), high strength (1000–1700 MPa), high ductility (10–30%), good corrosion resistance, and easy machinability. One of the strategic applications for these alloys is in ordnance, such as kinetic-energy penetrators.

In the study, a tungsten heavy alloy containing cobalt and molybdenum was subjected to thermo-mechanical processing that employed cyclic heat treatments in order to explore the possibility of enhancing mechanical properties. The alloy was synthesized by liquid phase sintering followed by heat treatments which consisted single as well as multiple cycles (Fig. 21). Subsequently, these were subjected to warm swaging imparting about 20% deformation.

Discernible changes were observed in the microstructure following cyclic heat treatment in both heat treatment and swaged conditions. Cyclic heat treatment results in separation of tungsten grains, thereby decrease in contiguity both in cobalt and molybdenum containing tungsten heavy alloys. While there was marginal improvement in tensile properties, impact toughness showed significant enhancement.

A detailed analysis of microstructure and fractographs was undertaken in order to understand the reasons for the enhancement in impact toughness and also the implication of these results in the development of heavy alloys with enhanced properties.

G S Tendolkar Award

Vijai Thavale, Assistant Professor, Department of Metallurgy and Materials Science, College of Engineering Pune, received the G S Tendolkar Award for the paper Forgeability of Astaloy and its Response to Thermal Processing, co-authored by N B Dhokey, S Dhokale and P Ghosh.

In the research work, forging was carried out as a secondary densification process on Astaloy (0.85% Mo+0.3% C) atomised powder (Fig. 22). Cold compaction of the powder was done at 600 MPa followed by sintering at 1120°C for 30 min. Three forging temperatures (800°C, 900°C and 1000°C) and three strain rates(0.1^{s-1}, 0.2^{s-1}, 0.3^{s-1}) were selected for forging parameters optimisation. Two surface treatments, namely carburising and carbonitriding, were carried out on the optimised forged samples. Powder shape and size was characterised using SEM and sieve analysis.

Cold compacted and sintered specimens were characterised for hardness, wear, density, tensile and transverse rupture strength. Microstructural characterisations of the differently treated specimens were carried out using optical microscope. The results indicated that forging at 1000°C and 0.3^{s-1} strain rate gave approximately 98% density and 90 HRB. Carbonitriding gave improved hardness and wear resistance than carburised steel.

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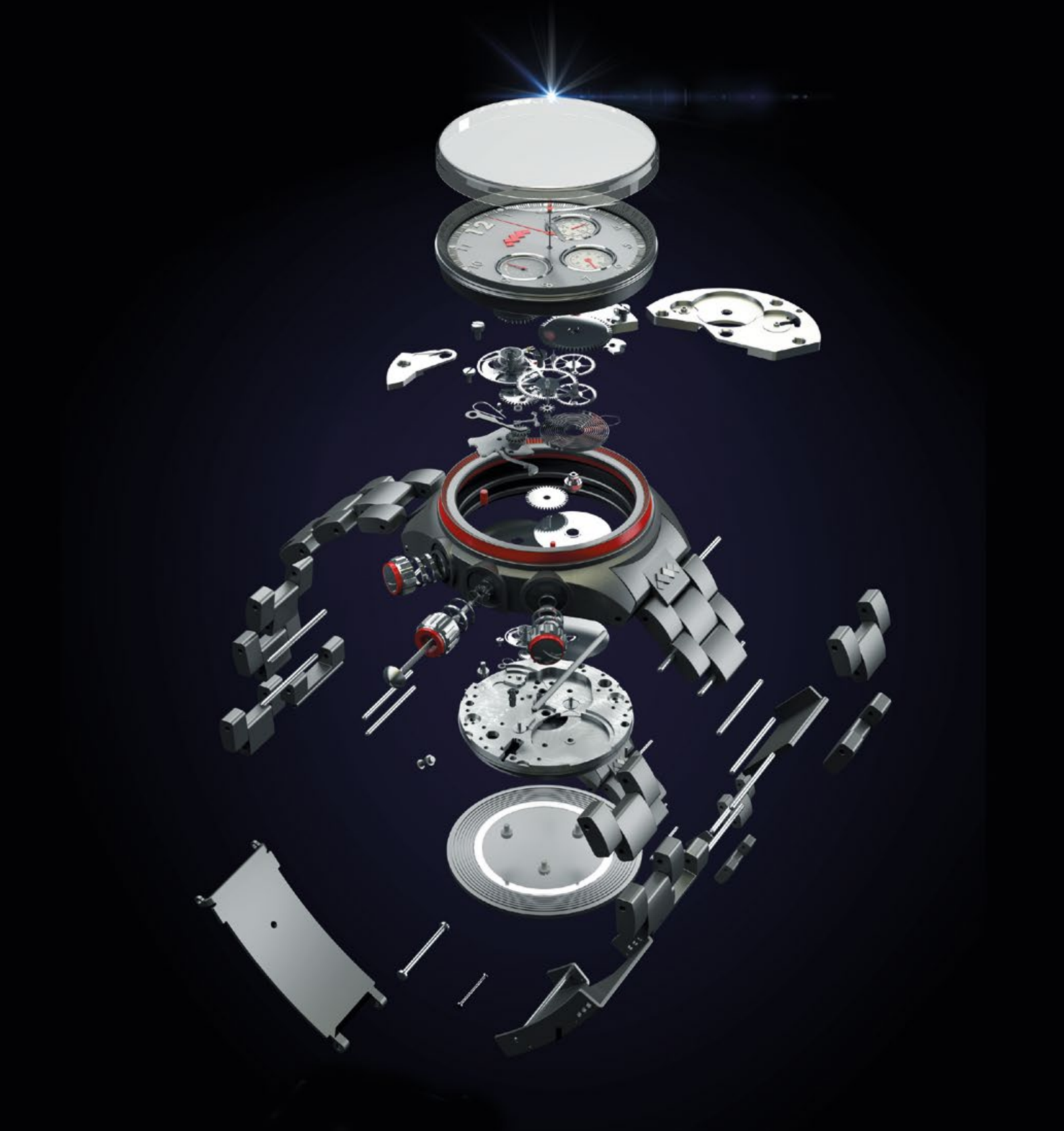

PM Industry Events

2016

AMPM2016 Additive Manufacturing with Powder Metallurgy
June 5–7, Boston, USA
ampm2016.org

POWDERMET2016 International Conference on Powder Metallurgy & Particulate Materials
June 5–8, Boston, USA
powdermet2016.org

ICMME 2016: 18th International Conference on Metal Materials and Engineering
June 27-28, Copenhagen, Denmark
www.waset.org

Additive Manufacturing Europe 2016
June 28-30, Amsterdam, The Netherlands
www.amshow-europe.com

EPMA Powder Metallurgy Summer School 2016
June 27 – July 1, Valencia, Spain
www.epma.com

Symposium and Exhibition on Additive Manufacturing (SEAM 2016)
July 26-27, Seberang Jaya - Penang, Malaysia
www.seam2016.com

ASIAMOLD 2016 - 3D Printing Asia
September 20-22, Guangzhou, China
www.asiamold-china.com

36th SENAFOR
October 5-7, Porto Alegre, Brazil
www.senafor.com

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

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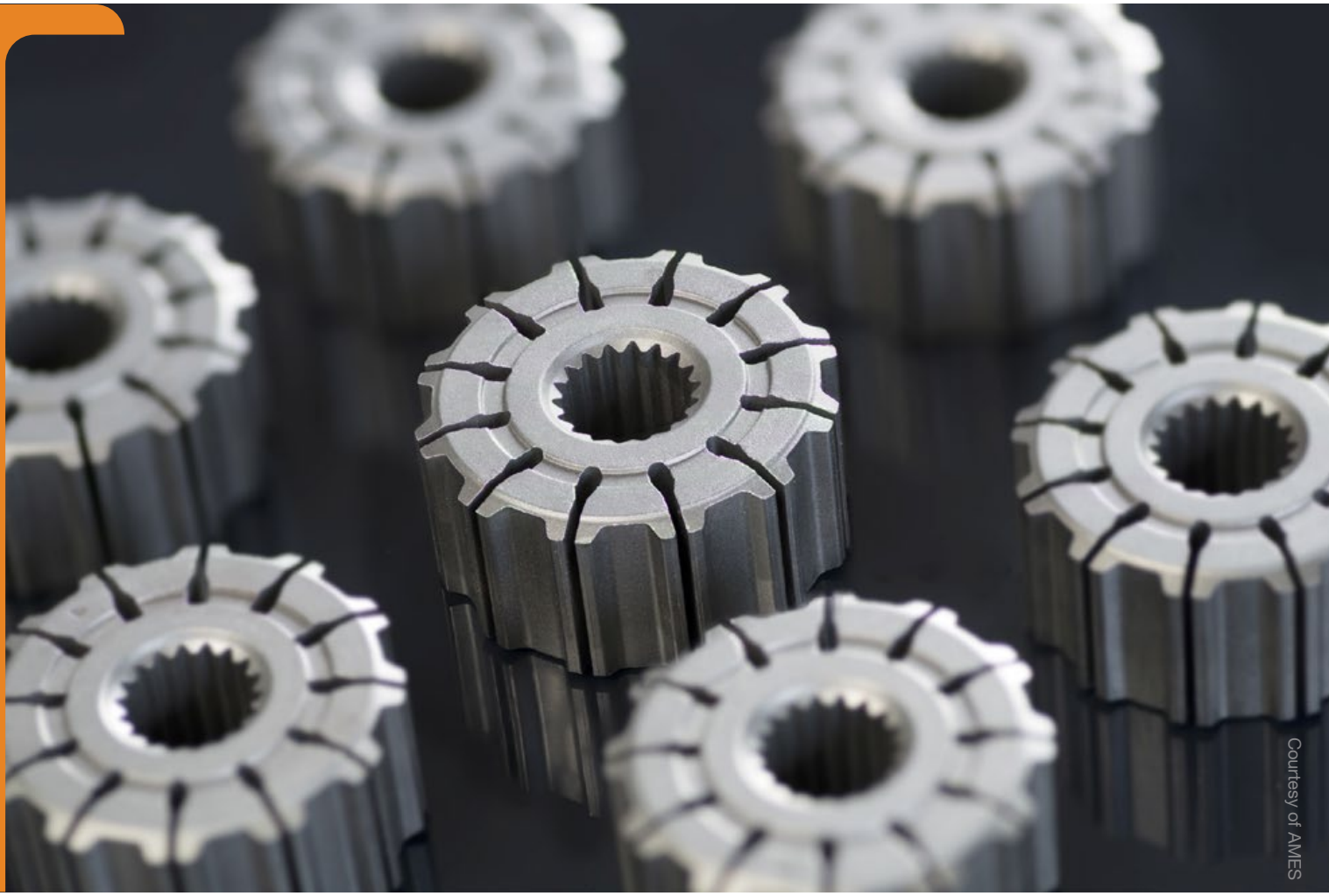

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