Metal Powder Solutions to Pomote Future Growth of the PM industry

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Abstract

The driving force for using PM compared to other manufacturing techniques is almost always due to its ability to produce structural components with close dimensional tolerances and the required performance in a cost-effective way. To further grow the PM market into new high challenging automotive applications, cost-effective PM material solutions combining higher precision with increased performance will be required. This can be achieved by different means. The development of new cost-effective alloy systems, new compaction techniques enabling higher densities, sintering at higher temperatures in combination with increased cooling rates, carbon control and adoption of secondary heat treatments, are all examples of ways that either on their own or in combination can be used to increase material performance. The growing awareness of sustainability also makes it important to select both material and manufacturing processes with the least impact on the environment.

In this paper some key aspects of the selection of suitable metal powder solutions and the processing conditions needed to meet performance requirements. These include cost-effectiveness and sustainability for automotive applications like synchronizing hubs, cam lobes, sprockets, gears and other demanding applications that will be presented in this paper.

Keywords: High Performance, High Precision, Productivity, Sustainability**.**

Introduction

The essential benefit of PM is that it provides a cost-effective shaping process, with virtually no loss of material, to mass produce components with close dimensional precision and the required mechanical properties. During recent years, PM materials used for structural components have gone through such favorable development that the properties of sintered steels today are comparable to those of wrought material see Figure 1. These achievements have been possible thanks to new advanced metal powders in combination with compaction tooling, presses and sintering furnaces utilizing the latest modern technology.

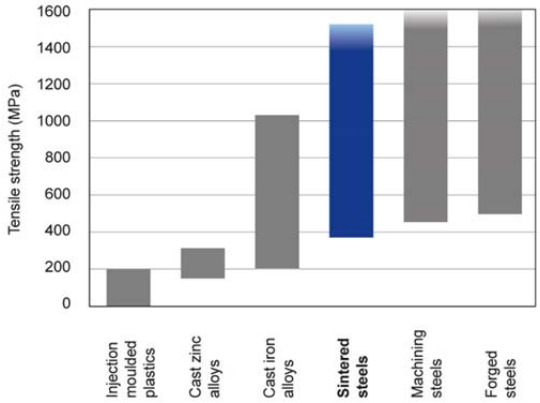


Figure 1. Comparison of tensile strength between PM and other materials.

To continue to expand the PM market into new demanding applications, cost effective metal powder solutions with increased performance will be required. Maintaining close tolerances is a prime objective and any alloying to improve mechanical properties must be made in such a manner that dimensional precision is maintained.

Competiveness of PM

The graph in Figure 2 below schematically illustrates a way to characterize the PM technology from a strength to dimensional tolerance capability perspective, depending on demands. Strength levels, defined as low, medium and high, are shown on one axis and dimensional tolerances, defined as medium, good and very good, are shown on the other axis. The competitiveness of PM compared to competing technologies such as casting, forging and machining etc. improves as both strength and tolerances increase. The best competitiveness is produced by the combination of high strength and very good dimensional tolerances seen in the upper right corner of the graph. It should also be pointed out that PM offers new design possibilities that can reduce weight and optimize stresses at different locations of the components. These features can be implemented already in the compaction process to enable cost-effective solutions.

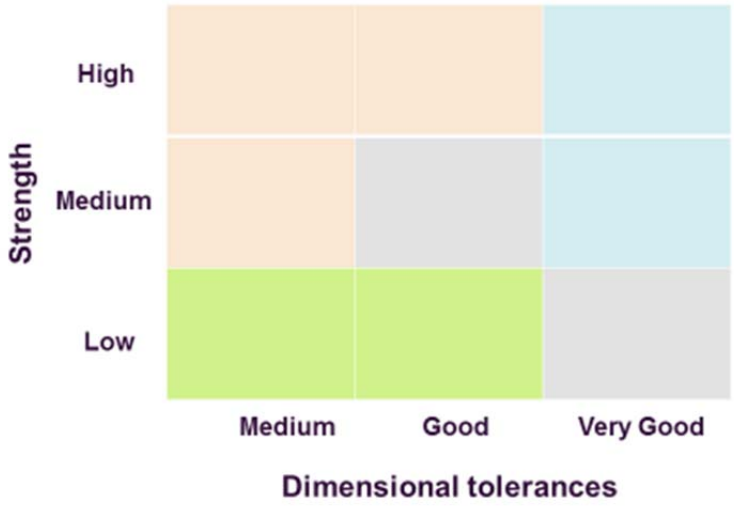


Figure 2: Capabilities of PM from a strength and dimensional tolerance perspective.

The green sections combine low strength with medium to good tolerances. Many existing PM applications fit into this category. Manufacturing costs are fairly low and density is typically below 7.0 g/cm^3 in combination with materials with no or very low amounts of alloying additions. Typical materials in this sector are alloyed with Cu and/or Carbon. Components in this

area are competing with low strength materials such as plastics and the stamping of steel sheet. This component category will continue to be important for PM but further cost reductions are necessary to secure this area for PM.

The tolerances can be improved from medium to good by either using diffusion alloyed Cu such as Distaloy ACu or by bonding using Starmix powder grades [1-4]. Further improved tolerances can be achieved by combining these. The Höganäs High Precision toolbox provides the best tolerances of all our materials – even better than Astaloy powders and Distaloy AB, AE [5].

An example of the improvement of tolerances is shown in Figure 3 [6]. In this study it was possible to reduce the dimensional scatter to half by utilizing both the diffusion bonding system for copper and by stabilizing the powder mix with organic binders according to the Starmix concept.

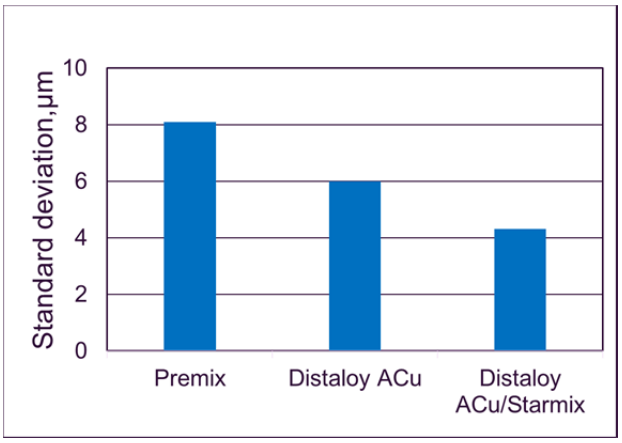


Figure 3. Dimensional tolerances of outer diameter (43 mm) of sintered gears made of Fe-2%Cu-0.8%C by 1) ordinary premix and Cu-met, 2) Cu added as Distaloy ACu and 3) same as mix 2 but bonded according to Starmix (750 parts/mix type).

The grey sections are defined with low strength and with very good dimensional tolerances. Those with medium strength and good tolerances represent strong, competitive areas for PM and many new future applications are possible. Further needs for very good dimensional tolerances can be achieved by utilizing diffusion alloyed powders or pre-alloyed powders, and each have their advantages. Organically bonded (graphite /alloying elements) powder, mixes as well as controlled component manufacturing processes, and these systems offer additional ways to improve precision. Components in these sections either have a high strength that is not possible to achieve with plastic or steel sheet, or very good dimensional tolerances achieved directly after processing, making other manufacturing technologies less competitive due to high manufacturing costs.

The light blue area has the highest potential for future growth into new applications, and this combines medium/high strength with very good dimensional tolerances. Close tolerances can eliminate or reduce machining operations and thereby avoid high manufacturing costs. The mechanical performance reaches that of cast, forged or machined wrought steels. Depending on processing conditions, powders of different types are suitable. Diffusion alloyed or pre-alloyed powders have their respective advantages. These materials are alloyed with elements with high hardenability effect such as Cu, Ni, Mo or Cr and can be adjusted to the demands of the component. Density of these components is normally above 7.1 g/cm^3. Close dimensional

tolerances can be achieved directly after sintering, and machining is limited to grinding or similar.

The pink areas are suitable for niche materials with properties that cannot be achieved with any other manufacturing method. Costs are high due to extensive machining and long production series are normally not feasible. However, PM material solutions in these sectors might have future potential with their unique properties and features.

High performance materials

In order to achieve mechanical properties comparable to wrought steel both alloying combinations with high hardenability and high density must be utilized. Besides alloying content, strength is determined by the sintering process in combination with the cooling rate. By using separate heat treatments such as through hardening or case carburizing, strength can be further improved. Density is of the greatest importance and this is preferably achieved directly during compaction to avoid large shrinkage during sintering. With subsequent processing operations, density can be further increased using local densification such as surface rolling, shot peening or re-striking. [7,8].

Pure, high-compressible iron powder and Mo pre-alloyed powders, diffusion alloyed with combinations of Cu, Ni and Mo are to date the most used materials for high performance applications. During recent years, a lot of research and development has been carried out to utilize Cr and Mn as alloying elements in PM. The driving force has been to utilize their hardenability and strengthening effect in combination with their cost-effectiveness. As these elements are prone to oxidization, the processing conditions for both powder- and component manufacturing are more demanding. The pre-alloyed Cr containing powders enable cost-effective mass production of high performance components. Some commercial high performance PM steels and their typical properties are described in Table 1 and Table 2 below.

Table 1. High performance PM steels and their compositions.

Material	Alloying Method	Alloying compositions			
		Cu	Ni	Mo	Cr
Distaloy AE	Diffusion alloyed	1.50	4.0	0.50	-
Distaloy HP	Diffusion alloyed + Pre-alloyed Mo	2.0	4.0	1.50	-
Astaloy CrA	Pre-alloyed	-	-	-	1.80
Astaloy CrM	Pre-alloyed	-	-	0.50	3.0

Typical mechanical performance of these materials after compaction and sintering at a conventional sintering temperature of 1120 °C and a high temperature 1250 °C are shown in Table 2.

Table 2. Typical properties after compaction at 600 MPa and sintering at 1120 °C resp. 1250°C for 30 min. 90 N_2/10H_2, cooling rate 0.5-1.0 °C/s.

Material	Tensile strength, MPa		Yield strength, MPa		Hardness, HV10		Elongation, %		Dim. Change, %	
Sint. Temp, °C	1120	1250	1120	1250	1120	1250	1120	1250	1120	1250
Distaloy AE 0,5% C	750	1050	420	720	220	300	2,5	1,5	-0,14	-0,80

Distaloy HP 0,5%C	830	1100	500	800	280	350	1,5	1,5	-0,15	-0,85
Astaloy CrA 0,5%C	650	910	460	750	180	220	2,2	2,5	-0,11	-0,65
Astaloy CrM 0,4%C	800	1100	600	850	240	310	1,1	2,0	-0,22	-0,75

It is clear that high temperature sintering is beneficial from a strength point of view for all four materials. The shrinkage however increases from a level of around 0.2 % at 1120 °C to 0.8 % at 1250 °C, which in turn influences the dimensional tolerances. All materials achieve a high hardness after high temperature sintering and sizing is therefore difficult. This makes it important to achieve very good tolerances after sintering to avoid or reduce machining. After sintering at 1120 °C tensile strength levels between 520 and 800 MPa are reached and after 1250 °C between 800 and 1100 MPa. The yield strength for the pre-alloyed chromium alloyed steels is higher than that of the diffusion alloyed steels due to the higher hardenability.

Life Cycle Assessment (LCA)

As most manufacturing methods influence the environment by consuming energy and other resources, today there is a growing awareness of aspects other than performance and costs for the selection of raw materials and production processes. It is thus necessary to evaluate and select both material and manufacturing processes with the least impact on the environment.

PM has two major environmental advantages: high material utilization and low energy consumption, Therefore, it is interesting to compare the environmental influence when manufacturing a component with either PM or by wrought steel. The systematic approach of Life Cycle Assessment, LCA, is one suitable means to carry out such a comparison [9, 10].

A comparative LCA study was carried out on an injection yoke used in a heavy truck application. The objective was to compare the environmental impact when producing a component either by machining of forged steel, or by PM technology. An additional objective was also to study the environmental impact by comparing two different PM materials: Astaloy CrM and Distaloy AE. Input data for the comparison is shown in Table 3.

Table 3. Injection yoke and data for LCA comparison between PM and wrought steel.

	Material	Weight component, g	Material utilization,%	Processing
Steel technology				
	SS2225 ISO-EN 25CrMoS4	194	68	Forging, Machining, Heat treatment
PM technology				
	Astaloy CrM-0.3%C	196	97	Compaction, Sinter hardening
	Distaloy AE-0.5%C	196	97	Compaction, Sintering, Heat treatment

The result of the analysis is shown in Figure 4 below. As can be seen both PM materials have an environmental advantage over the conventional wrought steel component. The process contribution in both cases is small in relation to the impact of the material. The LCA clearly demonstrates the lower environmental influence of the PM process when compared to machining with wrought steel..This advantage is primarily a result of the lower use of energy. As can be seen the environmental impact is substantially lower for PM compared to the machined components. The comparison between the two PM materials shows that the Cr containing material has a smaller environmental impact than the Ni, Cu and Mo alloyed materialprimarily due to the high content of Ni.

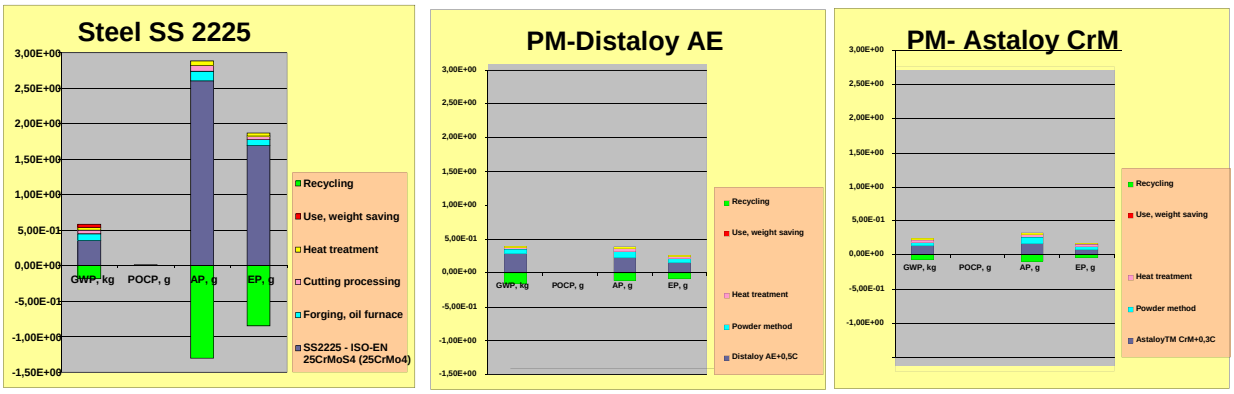


Figure 4. LCA results for Steel, SS 2225, compared with two PM materials, Distaloy AE and Astaloy CrM,

The results of the LCA study clearly show the advantages that PM technology offers compared to conventional wrought steel technology when producing high performance automotive components. The results also show the advantage of using PM materials alloyed with Cr instead of materials with high Ni content. Consequently, materials containing lower amounts of Ni would have less environmental impact, and additionally be more cost-effective due to lower amounts of costly alloying elements.

Lean Ni/Mo Material for heat treatment operation

In the following properties achievable after different heat treatment processing of Distaloy AQ, a lean Ni-Mo diffusion alloyed powder containing 0,5 % Ni and 0,5% Mo will be described [11] .

Test specimens according to ISO-standards were compacted at 700 MPa, both at room temperature (RT) and by warm compaction at 120 °C. Densities obtained at room temperature were about 7.15 g/cm^3, and for warm compaction about 7.30 g/cm^3. Gears for tooth root bending fatigue tests were compacted as can be seen in Figure 6. Two carbon levels were used: 0,2 % carbon for case hardening, and 0.6 % for through hardening.

All specimens were sintered in a mesh belt furnace at 1120 ^{0}C for 20 minutes in a 90/10 N_2/H_2 atmosphere with carbon potential. The cooling rate for the conventional sintering was approximately 1 ^{0}C/s. Through hardening was done at 860 °C for 20 minutes with a C-potential of 0.6 %. Case hardening was undertaken using the same conditions but with a higher C-potential of 0.8 %. All heat treated specimens were tempered at 200 ^{0}C for 60 minutes in air for stress relief.

The results are presented in Table 4 below. The apparent hardness (HV10) of the sintered Distaloy AQ specimens is in the range of 100-150, with the higher numbers indicating higher

carbon content. This rather low level facilitates sizing and coining after sintering when applicable. Hardness levels of 380 and 405 are achieved after through hardening. The corresponding values after case hardening are even higher 441 and 475. The higher hardness levels are obtained with the warm compacted materials. Sintered tensile strength varies in the range of 360 to 560 MPa with increasing numbers for warm compaction and higher carbon contents. Warm compaction has an even larger effect on the through hardened material, increasing tensile strength from 994 MPa to almost 1200 MPa.

Table 4. Properties obtained with Distaloy AQ after different processing.

Process	C%	Hardness, HV10		Tensile Strength, MPa	
		RT	Warm	RT	Warm
Sintered	0,20	105	113	357	395
Case hardened	0,20	440	475	-	-
Sintered	0,60	140	153	456	563
Through hardened	0,60	380	405	994	1196

Plane bending fatigue was tested at R=-1 and with a run out limit of $2x10^6$ cycles using the staircase method according to MPIF Standard 56. The endurance limit was determined at 50 % survival [12]. The results achieved are shown in Figure 6. The through hardened material achieved a slightly higher increase by warm compaction. The case hardened material shows an increase of more than 20 % by using warm compaction, reaching values above 500 MPa.

Tooth root bending fatigue was undertaken by applying a force on the tooth tips, as seen in Figure 6. Tests were made at R=0.1 using the staircase method with a run out limit of $3x10^6$ cycles. A fatigue limit of more than 700 MPa was achieved when combining warm compaction and case hardening of this material. The higher values for the warm compacted gears are due to a combination of higher density and finer pore size obtained by this compaction method.

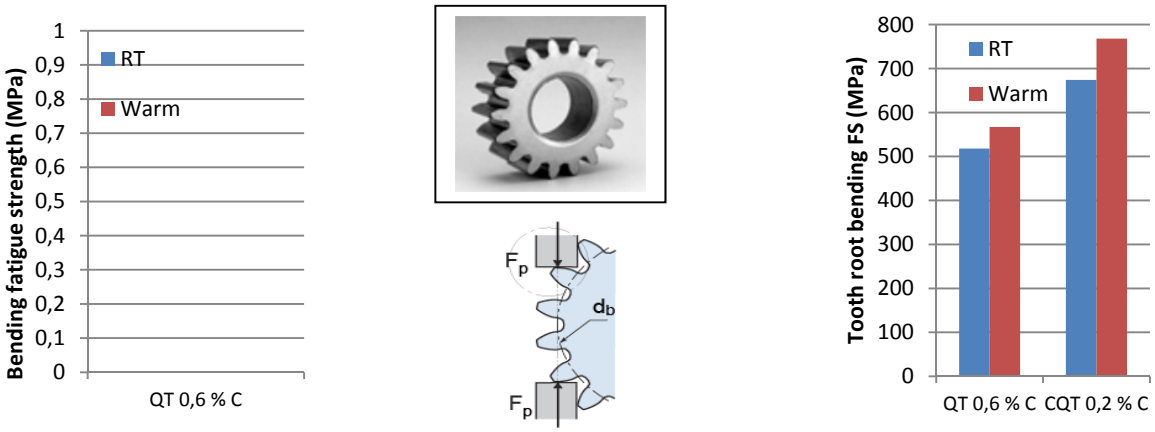


Figure 6. Plane bending fatigue strength (left), test gear and testing (center) and tooth root bending fatigue strength (right) for Distaloy AQ in through hardened and case hardened condition.

The through hardened material is fully martensitic with some small Ni-rich austenitic areas both at the surface and in the centre. The case hardened material shows the same structure at the

surface as the through hardened material, whereas the centre consists of martensite, perlite, ferrite and Ni-rich austenite. The micro hardness at the surface was measured to HV0,1=700.

PM Applications suitable for Cr alloyed low alloyed PM steels

The properties achievable with Cr alloyed materials such as Astaloy CrA and Astaloy CrM, make them very suitable for new demanding applications requiring high performance in combination with cost-effectiveness. Examples of such applications are briefly discussed in the following.

Synchronizing hubs

Today many high performance synchronizing hubs are produced using different diffusion bonded materials like Distaloy AE and Distaloy HP. With new demands for higher hardness, yield and fatigue strength in combination with high toughness and tight tolerances, there is a need to move to materials and processes with a better cost/performance ratio. New designs for synchronizing hubs are in general also more complicated in shape, with complex multi-level designs and thin wall sections. To successfully manufacture such new hubs, more complex tool concepts, effective powder filling and advanced compaction control is required. By using different types of bonded mixes, more effective powder filling with an even and faster fill can be obtained. The bonding of fine constituents will also improve tolerances as alloying elements are becoming more evenly distributed, and the working environment is improving due to reduced dusting.

Regarding mechanical properties, it is important to tailor the material composition based on the requirements and the processing conditions that are available. Sinter hardening, combining good manufacturing economy with the ability to achieve unique combinations of mechanical properties has proven to be a very cost-effective process route for high performance synchronizing hubs. The two pre-alloyed Cr materials presented above are suitable candidates to fulfill these new requirements. In the following, properties achievable with these materials after sinter hardening will be described.

Sinter hardening of Cr materials

To take sufficient hardening under typical sinter hardening conditions, the Astaloy CrA material needs an addition of 1-2 % of either Cu or Ni, whereas the Astaloy CrM material takes hardening as it is. Test specimens according to ISO-standards were compacted at 700 MPa both at room temperature (RT) and by warm compaction at 120 °C (8). Densities obtained at room temperature were around 7.15 g/cm^3 and for warm compaction about 7.30 g/cm^3. All specimens were sintered in a mesh belt furnace at 1120 ^{0}C for 20 minutes in a 90/10 N_2/H_2 atmosphere with carbon potential. The cooling rate was approximately 3 ^{0}C/s [13].

The chromium pre-alloyed materials show good response to warm compaction with increased sintered densities in the range of 0.15 g/cm^3. The increased density results in increased tensile properties as can be seen in Figure 7. For conventional compaction, tensile strength is in the range of 1060-1160 MPa. With warm compaction the tensile strength levels increased to 1190-1260 MPa with the highest values for Astaloy CrA-2Ni [13]. Hardness follows the same pattern as that of tensile strength.

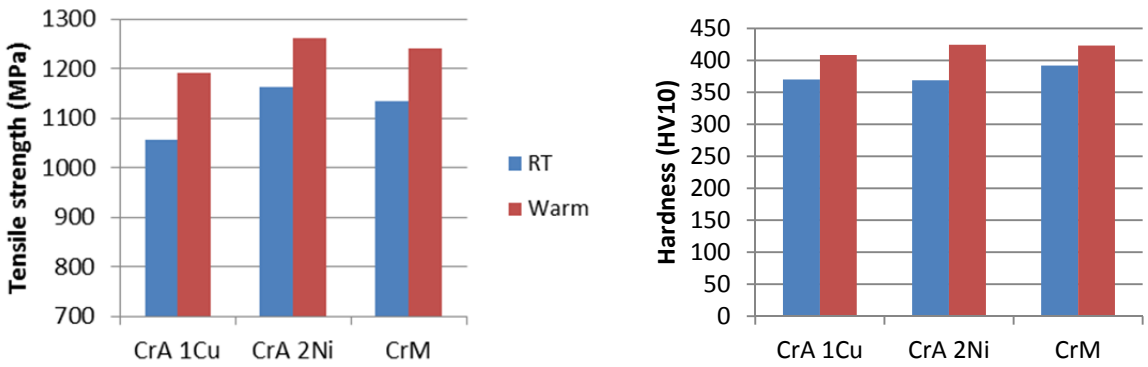


Figure 7. Tensile strength and hardness for Astaloy CrA with Cu and Ni added, and Astaloy CrM in sinter hardened and tempered condition.

The plane bending fatigue strength in Figure 8, shows the biggest increase for Astaloy CrA-1Cu, whereas the warm compacted Astaloy CrA-2Ni shows the highest fatigue strength.

For the plain Astaloy CrM material, a fatigue strength of 363 MPa was obtained. These high mechanical properties and hardness are due to the high amount of martensite obtained after sinter hardening, and the higher density of the warm compacted materials.

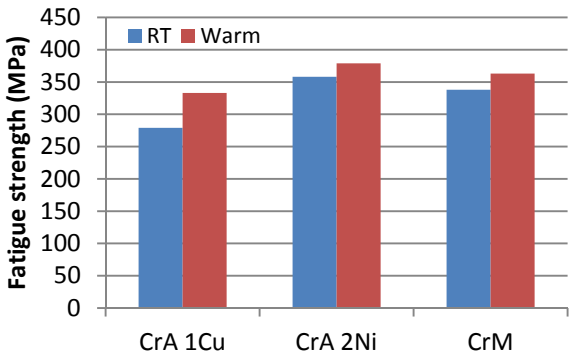


Figure 8.Plane bending fatigue strength of conventionally warm compacted Astaloy CrA with Cu or Ni added, and Astaloy CrM in the sinter hardened and tempered condition.

Belt pulleys/Sprockets

PM components are commonly used in applications where they are exposed to different degrees of wear. Various heat treatments are often used to increase hardness and thereby wear resistance. Belt pulleys for water pumps and fuel injection are typical PM applications that have been on the market for many years. Today the global market for cars is growing both volume wise and geographically. As a consequence, more cars will be used under more severe conditions creating new requirements on the pulleys performance of the pulleys. Hard particles in dust are able to get into the system and create more severe abrasive wear on the pulleys which may lead to severe damage of the engines.

An investigation to evaluate the potential to decrease wear on a pulley by utilizing a Cr material combined with steam treatment and nitro carburising, was therefore carried out [14]. Two different materials were studied. One was Fe-2%Cu-0.5%C, a typical composition used for pulleys today. The second material was Astaloy CrA with 0.35 %C, and an addition of 0.30 %

MnS in order to facilitate machining. Different samples were prepared and sintered at 1120 ˚C for 30 minutes in 90/10 N_2/H_2 atmosphere. Steam treatment and nitro-carburising were carried out in production batch furnaces.

Wear testing was done using the ASTM G65-04 standard, dry sand-rubber wheel method for abrasive wear. Figure 9 shows how the equipment was set up. Results from the tests are summarized in Figure 10. The wear resistance, expressed as adjusted volume loss, AVL, shows that the Fe-Cu-C material experienced a considerably larger volume loss of 18.2 mm^3 when compared to the 11.3 mm^3 for Astaloy CrA. This difference can be explained by differences in the microstructure. The Fe-Cu-C material contains a mixture of ferrite and perlite, whereas the Astaloy CrA material has a very fine perlitic structure which improves the wear resistance.

After steam treatment the volume losses are reduced to 10.2 and 8.7 mm^3, respectively. During steam treatment an oxide layer of 2-5 µm is formed. In this condition there is little difference in wear resistance between the materials.

Applying nitro-carburising reduces the volume loss to 5.4 mm^3 , half that of steam treated, for the Fe-Cu-C. For the The Astaloy CrA is reduced even further to 2,6 mm^3. The Astaloy CrA material with addition of MnS showed an even smaller wear of 0,7 mm^3. This is probably due to higher carbon content in this series resulting in finer pearlite with higher hardness than the effect of MnS addition.

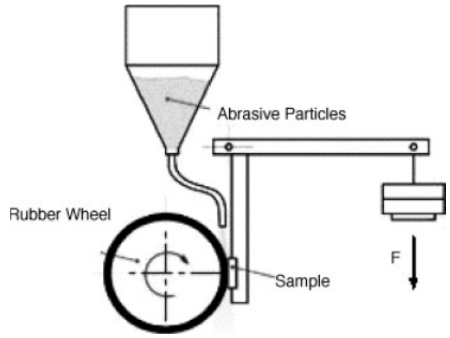


Figure 9. Schematic picture of the dry sand-rubber wheel testing equipment used in the standard test method ASTM G65 for abrasive wear.

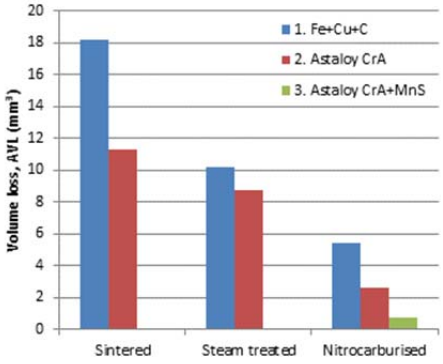


Figure 10. Wear resistance expressed as Adjusted Volume Loss, AVL, according to the ASTM G65 standard.

Cam lobes

PM has for many years been utilized to produce cam lobes for different automotive cam shaft systems. However, the development of new engine solutions with increased performance has in recent years led to many systems that previously used PM have changed to other material solutions. Many systems now use forged steel because the contact stresses are very high, making PM materials unsuitable due to their porosity. In systems with high sliding wear requirements, different solutions based on chilled cast iron are dominant. Typical Hertzian contact pressure levels used in these systems are around 1000 MPa. PM offers many options to cost effectively produce cam lobe materials with good wear performance. With an ability to operate at these load levels, this could open up new opportunities for PM.

In order to compare the performance of a new PM material concept with a chilled cast iron material (CCI), a friction and wear testing was undertaken by simulating a cam lobe to tappet follower contact using crossed cylinders [15].

The PM material used was a mix of Astaloy CrA (80 %) and Astaloy CrM (20 %) with 0.8 %C and 0.5 %MnS. Specimens were compacted to a density of 7.2 g/cm^3 and sinter-hardened at 1120 °C with a cooling rate of 2.5 °C/s. The microstructure obtained after this processing is shown in Figure 12. As can be seen, it consists of fine pearlite with martensite areas. Reference material was chilled cast iron, GJS-type with nodular graphite and a hardness of 54 HRC, from an automotive cam lobe application.

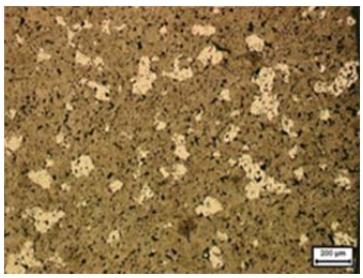


Figure 12 A

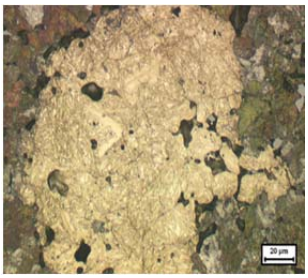


Figure 12 B

Figure 12. (A) Shows fine pearlite with martensite. (B) Close up of martensitic area.

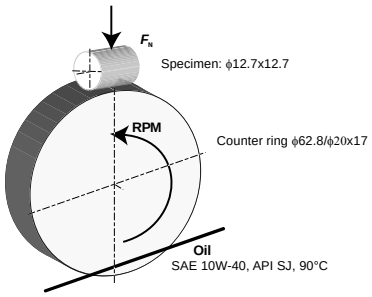


Figure 13. Crossed cylinders test setup

Friction and wear testing was done using crossed cylinders contact as shown in Figure 13. After 23 hours wear tests at a load of 800 MPa and 0.5 m/s sliding velocity, corresponding to 40 km sliding distance, both reference and sintered specimens experienced safe, mild wear. The sintered materials had constant coefficient for friction of 0.11 while the reference specimen steadily decreased from 0.17 to a uniform 0.12 by the end of the test run. The crossed cylinder simulating wear test showed that the Cr based PM materials provide a safe, mild wear equal to the level of reference specimens but with lower friction.

Gear applications

A goal for many years, has been to apply the benefits of PM to the production of heavy loaded gears such as automotive transmission gears. PM offers many advantages for the design of gears, enabling production of new designs that are not possible to carry out with traditional machining operations and equipment in a cost-effective way.

The presence of porosity in the sintered component often has negative connotations. However, the increased dampening properties associated with internal porosity can carry potential benefits such as noise suppression. Investigations at many institutes have concluded that due to the influence of porosity, PM steels provide a damping effect. This can be a substantial benefit when applied in E drive applications where noise and vibration harshness will be very important.

The data presented above for the lean Distaloy AQ material after different heat treatment operations with gears show that lean PM materials can provide properties which make it highly suitable for many different gear applications utilizing smaller gears. For larger size gears other materials such as the Cr materials described might be more suitable.

A major challenge for the PM industry is to establish PM gears as a choice for automotive transmissions. Joint efforts are required to review new materials, material data, processes and designs in order to enable this transformation. The potential is huge and tapping into this could open up a significant market for the PM industry.

Discussion and Conclusions

The two main criteria for the competitiveness of powder metallurgy are strength and dimensional tolerances. High strength and very good tolerances is the combination offering the highest potential for growth. However, only a small amount of the total PM components produced today belong to this group. Low and medium strength in combination with good tolerances are today representing the bulk of PM parts. Components in this area are competing with low strength materials such as plastics and steel sheet forming. Greater cost-effectiveness is the only way for PM to compete in this area.

Very good dimensional tolerances can be achieved by utilizing diffusion alloyed powders or pre-alloyed powders that have their respective advantages. Organically bonded powder mixes, as well as controlled component manufacturing processes and systems, offer additional ways to improve precision. Components in these areas either offer a high strength not possible to achieve with plastic or steel sheet, or offer very good dimensional tolerances directly after processing, which makes other manufacturing technologies less competitive due to high manufacturing costs.

Components characterized by very good dimensional tolerances in combination with medium to high strength have the highest future growth potential. The low alloyed steels presented in this paper are all examples of materials that after different processing offer performance levels that provide opportunities for many new challenging applications. The LCA comparison shows that PM has an environmental advantage when compared to steel components. The PM material containing Cr is advantageous when compared to the material containing Ni. Distaloy AQ is an example of a lean cost-efficient alternative for applications that require heat treatments. Data for case hardening shows that bending fatigue limits above 500 MPa can be obtained, and tooth root bending fatigue limits close to 700 MPa. This opens up possibilities for cost-effective manufacturing of new gear applications and other high performance applications requiring heat treatment.

Cr is a cost effective alloying element which promotes hardenability and strength in PM steels. By utilizing commercial pre-alloyed Cr powders, high performance PM steels can be produced by sintering at 1120 °C in nitrogen /hydrogen atmospheres. Tensile strength levels in the range of 1050-1250 MPa and a plane bending fatigue strength of 450 MPa can be obtained by sinter hardening. These mechanical properties make the pre-alloyed Cr materials suitable for new high performance applications like synchronizing components, sprockets, cam lobes and others.

A challenge for suppliers to the automotive industry and other industry segments, producing large numbers of identical products, is to not only meet the demands for performance, quality and costs, but to also be at the frontline of new developments. The PM industry and its capabilities are still rather unknown to many designers, in comparison to other manufacturing technologies such as casting, forging and machining of base stock. This potential offers the opportunity for PM to make new, as yet unknown improvements and capitalize on this to strengthen its competitiveness.

References

1 M. Larsson and H. Vidarsson: Efficient bonding for Dimensional Stability, Proceedings of PM2TEC2000, New York, May/June 2000.
2. P. Lindskog: Dimensional Accuracy, Microstructure and Mechanical Properties of Parts Made

from Some High Strength Sintered Steels, Proceedings of 4th European Symposium of Powder Metallurgy in Grenoble, France, May 1975.
3. C. Lindberg, K. Ishi and T. Tsuboi: Material with Stable Dimensional Change Independent of Internal Density Variations, PM 93, Kyoto, Japan, July 1993.
4. H. Vidarsson and J Arvidsson: Die Filling Capability of Powder Mixes, Proceedings of Powder Metallurgy World Congress 2000, Kyoto, Japan, November 2000.
5. Höganäs High Precision Toolbox, www.hoganas.com/toolbox
6. J. Tengzelius, Advances in steel powders for high performance PM parts, PMAsia2005, Shanghai, China, April 4, 2005
7. C. Lindberg, B Johansson and B Maroli: Mechanical Properties of Warm Compacted Astaloy CrM, Proceedings of PM2TEC2000, New York, May/June 20005. IVF report 84-813
8. S. Berg and B. Maroli: *Properties Obtained by Chromium-Containing Material,* Advances in Powder Metallurgy & Particular Materials, 20021.
9. IDEMAT, LCI data base, http://www.idemat.nl/index.htm)
10. Ecoinvent, LCI data base, http://www.ecoinvent.ch/)
11. U. Engström et al, EURO PM2011, Barcelona, October 10-13, 2011
12. C. Larsson et al. EURO PM2012, Basel, September16-19, 2012
13. C. Larsson, U Engström. *High Performance Sinter Hardening Materials for Synchronizing Hubs,* EURO PM2011 in Barcelona, October 10, 2011
14. C.Larsson, U. Engström, Aspects of nitro-carburising of PM materials for improved wear resistance. EURO PM 2013 in Gothenburg, on September 17, 20131
15. S. Dizdar, H. Grosser, U. Engström, Friction and wear characterization of sintered low alloyed chromium steels for structural components