From raw material to new challenging applications

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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 required performance in a cost effective way. Nowadays there is also a growing awareness of other aspects than cost on the selection of raw materials and production processes. Most manufacturing methods have an impact on the environment in the sense that it consumes energy and resources. It is thus necessary to select both material and process with the least impact on the environment. In this presentation some key aspects on the selection of raw materials, alloy compositions and processing conditions are discussed regarding performance requirements, cost effectiveness and environmental impact for some new challenging PM applications.

Introduction

During the years PM materials used for structural components have gone through favorable development, that properties of sintered steels today are comparable to those of wrought materials, figure 1. To continue to expand the PM market into new demanding applications, cost effective materials with increased performance will be required. By using lower cost alloying elements such as Cr and Mn, or by utilizing the more expensive elements Cu, Ni and Mo more efficiently, the alloying cost of high strength sintered steels can be substantially reduced.

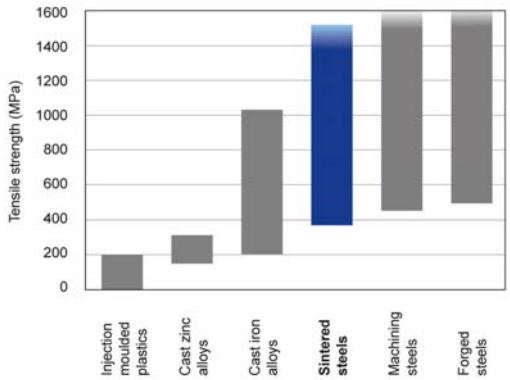


Figure 1. Comparison of tensile strength between PM and other materials

Alloying elements and methods used in PM

During the years lots of research and development have 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. However, as both elements are very prone to oxidization, the processing conditions for both powder -and component manufacturing are more demanding. By utilizing Master alloys containing high amount of Cr and Mn in combination with high temperature sintering, >1200°C, a number of Cr and Mn materials have been brought to the market during the years. Strength levels exceeding 800 MPa are reported for such materials after high temperature sintering (1). As the oxidation potential for Cr and Mn decreases with decreasing concentration, pre-alloyed powders are advantageous from this point of view. However, the oxides formed on the particle surfaces during water atomization have to be reduced during the following annealing procedure. Due to the high stability of Cr and Mn oxides the annealing conditions used are more demanding than for conventional iron powders (2, 3). As Mn has even higher affinity to oxygen and is more challenging to handle during sintering, a number of pre-alloyed Cr materials have been developed during the last years. These can all be sintered at normal belt furnace sintering conditions, i.e. at 1120°C in nitrogen and hydrogen mix atmospheres as long as partial pressure of oxygen is lower than 5*10-18 atm (4). Conventional endogas is therefore not suitable for sintering of these materials. The now commercial pre-alloyed Cr containing powders in combination with sinter

hardening enable cost effective manufacturing of high performance materials for new challenging applications for PM.
However, today there is also a growing awareness of other aspects than cost on the selection of raw materials and production processes as most manufacturing methods influence the environment by consuming energy and other resources. It is thus necessary to evaluate and select both material and manufacturing processes with the least impact on the environment.

LCA comparison between components manufactured in powder technology vs. conventional steel technology

A major issue to consider for industries in the modern society is the environment and the influence of their activities on the ecological system both for existing and future generations. 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 LCA (Life Cycle Assessment) is one suitable means to carry out such a comparison. The LCA includes the following four steps: Goal and system border, Inventory (LCI), Assessment of Impact and Interpretation of results. Each of these steps are briefly described in the following.

Goal and system borders

The system border of the study defines what activities that should be regarded and which activities that lies outside of the interest of the study. The intention is to set system borders in order to include all important and relevant environmental impact of the compared systems. The system border for this study was set according to applicable ISO standards in the 14040 series and is outlined in figure 2.

Inventory

The inventory is the most comprehensive and time consuming part of the work and includes collection of all environmental impact occurring inside the defined system border. Inventory data has been taken from different sources, real production data and data from LCI databases (5, 6, 7).

Assessment of environmental impact

The inventory phase results in a lot of data about emissions from activities inside the system border of the study. To draw conclusions from this rather complicated picture emission data need to be classified and characterised into known environmental impact factors. It should also be recognised that a certain emission may influence more than one impact factor.

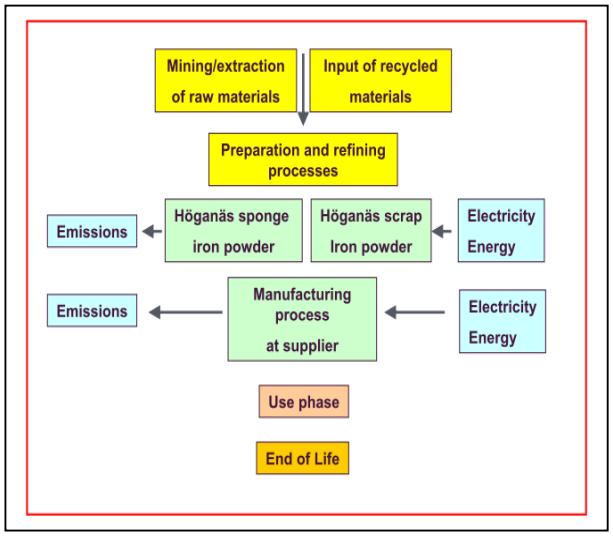


Figure 2.System border of the LCA study

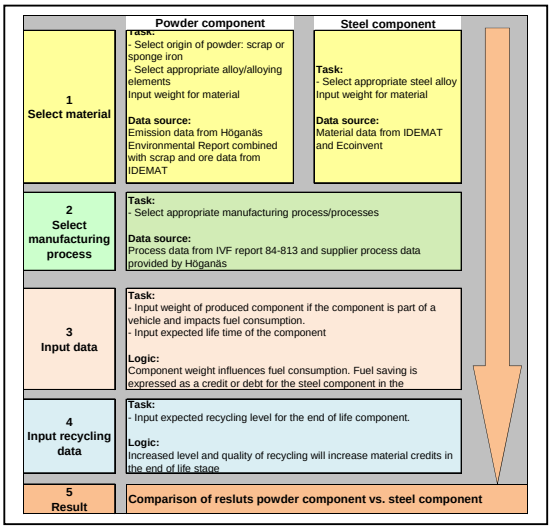


Figure 3. Outline of calculation model

Calculation model

To calculate environmental impact for different design solutions a general model enabling a comparison between components made by PM technology and by conventional wrought steel

technology was used, figure3. A relevant comparison can only be made between components fulfilling the same technical function and having comparable technical properties.

The environmental impact is calculated and expressed in Global Warming Potential (GWP), Photochemical Ozone Creation Potential (POCP), Acidification Potential (AP) and Eutrophication Potential (EP). .

Injection yoke analysis

A comparative LCA study was carried out on the injection yoke shown in Figure 4.

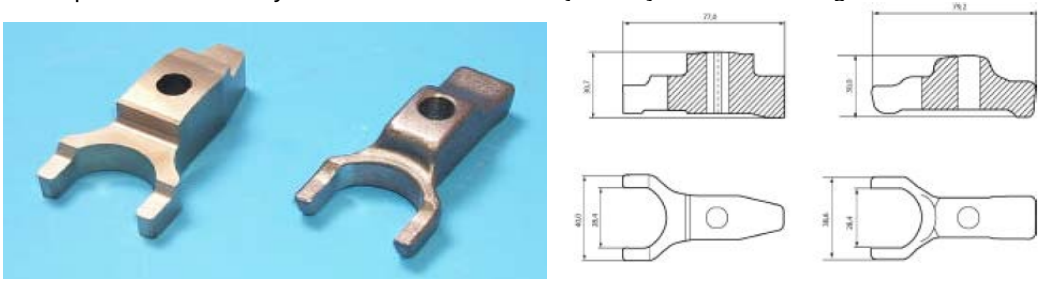


Figure 4. Injection yoke, PM yoke to left, forged steel yoke right.

Objective was to compare the environmental impact when producing a component either by machining of forged steel or by PM technology. Another objective was to study the environmental impact by comparing two different PM materials made from steel scrap, Astaloy CrM and Distaloy AE. Astaloy CrM is a pre-alloyed material containing 3.0% Cr and 0.5% Mo. Distaloy AE is a diffusion alloyed material containing 4.0%Ni, 1.5%Cu and 0.5% Mo. Both materials are suitable for high strength applications. Input data for the comparison is given in table 1.

Table 1. Input data for comparisons between PM and wrought steel for injection yoke

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

Results and discussion The result of the analysis is shown in figure 5 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. This LCA clearly demonstrates the lower environmental influence of the PM process compared to machining of wrought steel route. This advantage is primarily a result of the lower use of energy. Environmental impacts such as depletion of natural resources, acidification and eutrophication are substantially lower for PM compared to the figures for machined components. The comparison between the two PM materials shows that the chromium containing material has a smaller environmental impact than the Ni, Cu and Mo alloyed material. The higher figure for this material is primarily related to the high content of Ni.

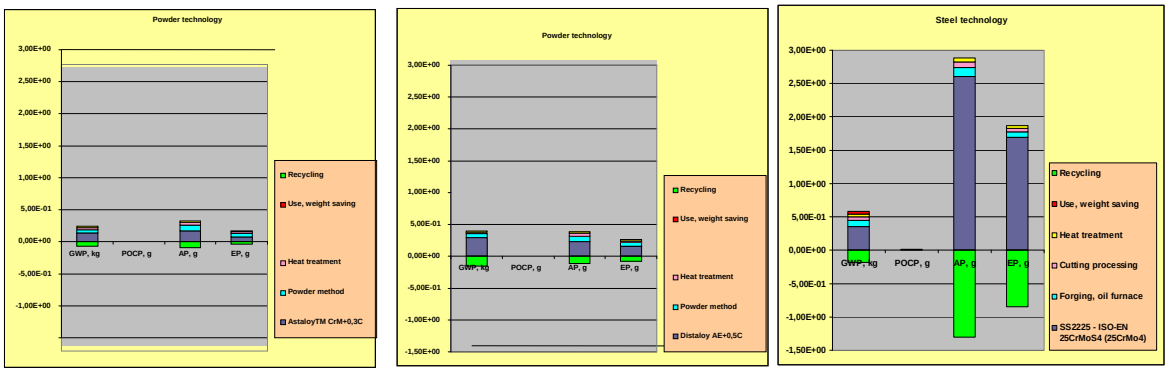


Figure 5. Astaloy CrM/0,3%C, Distaloy AE/0.5%C compared to SS 2225

Next level high performance materials for new challenging applications

The results of the LCA study presented in previous section clearly show the advantages the PM technology offers compared to conventional wrought steel technology to produce high performance automotive components. The results also show the advantage to use PM materials alloyed with Cr instead of materials with high Ni content. Consequently materials containing lower amount of Ni would give less environmental impact. The objective of this last part of this paper is to demonstrate properties achievable with a new lean Ni-Mo diffusion alloyed powder, Distaloy AQ, and two Cr pre-alloyed powders. After different processing routes materials based on these powders exhibit properties suitable for new high performance applications like synchronizing hubs, cam lobes, transmission gears and other challenging applications.

Materials and experimental procedures

Three different base powders have been evaluated in this study. For sintering and heat treatment the lean diffusion alloyed powder Distaloy AQ containing 0,5 % Ni and 0,5% Mo respectively was used and for sinter hardening, the two pre-alloyed Cr-containing materials, Astaloy CrA with 1,8%Cr and Astaloy CrM with 3,0%Cr and 0,5%Mo. Distaloy AQ was tested with 0,2% carbon for case hardening and 0,6 % for through hardening. Astaloy CrA needs an addition of 1.0%Cu or 1,0%Ni to take hardening under typical sinter hardening conditions, whereas the Astaloy CrM takes hardening as it is. For room temperature compaction (RT), Premixes with 0,8 % Amide-wax were used. Warm compaction was done with Densmix powders made for this purpose (8). The additives used were fine synthetic graphite, Timcal F10, atomized copper powder -100 mesh and fine carbonyl nickel powder, Inco 123.

Tensile, impact and fatigue test specimens according to ISO-standards were compacted using a 60-ton hydraulic press at 700 MPa. The Premixes were compacted at room temperature (RT) and the Densmixes were warm compacted at 120°C. The densities obtained at room temperature were about 7,15 g/cm^3 and for warm compaction about 7,30 g/cm^3. Additionally, for tooth root bending fatigue tests gears with 18 teeth and an outer diameter of 32 mm were compacted, figure 5.

All test 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 and for the sinter hardening approximately 3^{0}C/s. Through hardening of Distaloy AQ was done at 860°C for 20 minutes at a C-potential of 0,6 %. The case hardening was done at the same conditions but with a higher C-potential of 0,8 %. Both the sinter hardened and heat treated specimens were tempered at 200^{0}C for 60 minutes in air for stress relief. 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. The tooth root bending fatigue was done by applying a force on the tooth tips of a gear as shown in figure 5. Tests were made at R=0,1, using the staircase method, with a run out limit of 3x10^6 cycles.

Results for sintered and heat treated Distaloy AQ material

The results are presented in table 2 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 seen for 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 2. 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

The plain bending fatigue strength was evaluated for through and case hardened materials (9). By applying warm compaction there is a small increase for the through hardened material, figure 6. The case hardened material shows an increase of more than 20 % by using warm compaction, reaching values above 500 MPa for the fatigue limit at 50% survival. The trend is the same for the tooth root bending fatigue measured on the gears. Here, a fatigue limit of more than 700 MPa is achieved when combining warm compaction and case hardening of Distaloy AQ. The higher values for the warm compacted gears can be explained by a combination of higher density and finer pore size obtained by this compaction technique.

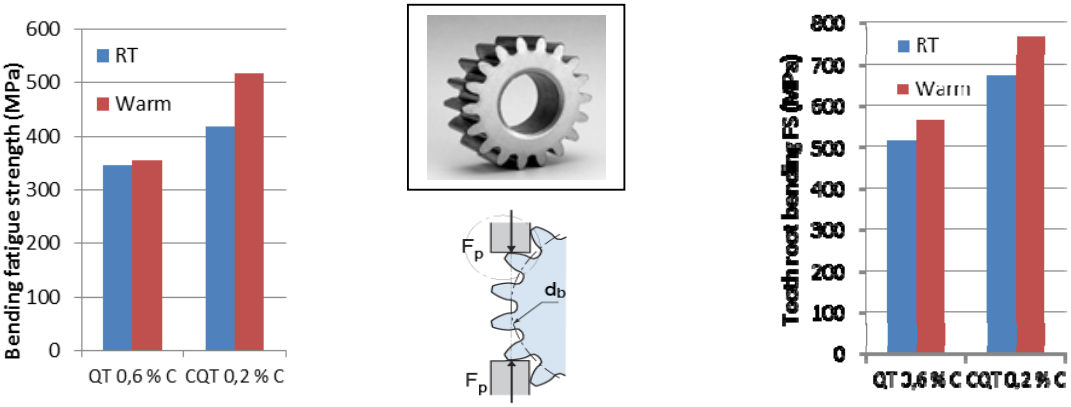


Figure 6. Plane bending fatigue strength (left), test gear and testing (center) and tooth root bending fatigue strength (right) for Distaloy AQ in through hardened and case hardened condition.

The microstructure of sintered Distaloy AQ with 0,2%C is mainly ferritic with some perlitic areas.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.

Results of sinter hardened Cr materials

The chromium pre-alloyed materials show good response to warm compaction with increased sintered densities in the range of 0,15 g/cm^3. For Astaloy CrA + 2 % Ni this leads to a sintered density of 7,25 g/cm^3 , figure7. The increased density results in increased tensile properties. For conventional compaction tensile strength is in the range of 1060-1160 MPa. By warm compaction the tensile strength levels increased to 1190-1260 MPa with the highest values for Astaloy CrA + 2 % Ni (10).

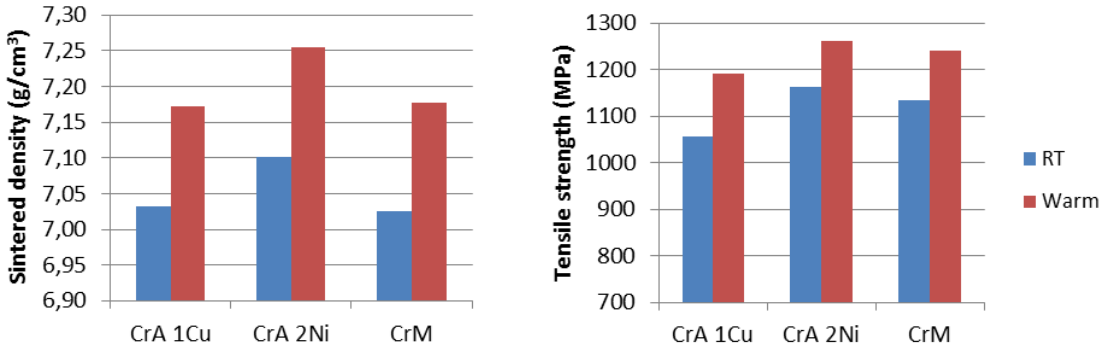


Figure 7. Sintered density and tensile strength for Astaloy CrA with Cu or Ni added and Astaloy CrM in sinter hardened and tempered condition.

Hardness and fatigue strength follow the same pattern as the tensile strength, figure 8. The plane bending fatigue strength shows the largest increase for the Astaloy CrA + Cu, whereas the warm compacted Astaloy CrA + 2 % Ni shows the highest fatigue strength, 379 MPa at 50 % survival. By creating a higher C-content at the surface even higher fatigue strength, 447 MPa, can be achieved. For the plain Astaloy CrM material 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. The properties achievable with both Cr alloyed materials, Astaloy CrA and CrM, make these very suitable for new demanding applications requiring high performance in combination with cost effectiveness. Examples of such applications are synchronizing components like hubs and sleeves, sprockets and cam lobes.

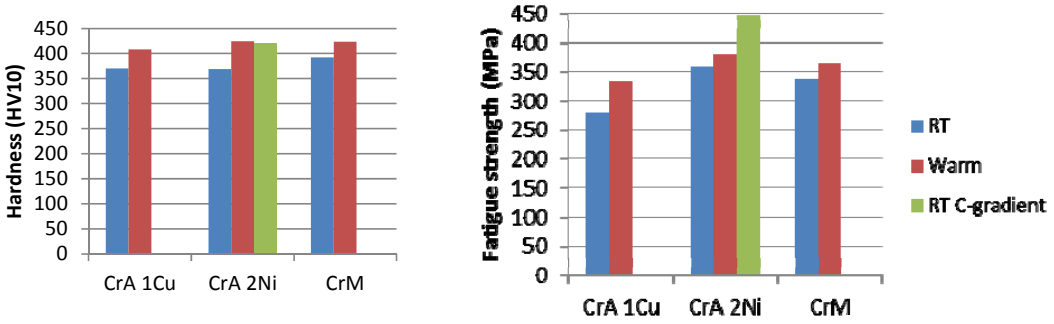


Figure 8.Vickers hardness and plane bending fatigue strength of conventionally and warm compacted Astaloy CrA with Cu or Ni added and Astaloy CrM in the sinter hardened and tempered condition.

Conclusions

The LCA comparison shows that PM has an environmental advantage compared to the steel component. The Cr containing PM material is advantageous compared to the Ni containing one.

Distaloy AQ is a lean cost efficient alternative for applications that are through hardened or surface heat treated. Case hardened data show that bending fatigue limits above 500 MPa can be obtained. Tooth root bending fatigue limit of almost 700 MPa is achieved by combining warm compaction and case hardening. This opens up possibilities for cost effective manufacturing of new gear applications and other high performance applications requiring heat treament .

Cr is a cost effective alloying element which promotes hardenability and strength of PM steels. By utilizing pre-alloyed Cr powders high performance PM steels can be produced by sintering at 1120°C in nitrogen /hydrogen atmospheres. The powders also show good response to warm compaction resulting in increased density of about 0,15 g/cm^3 compared to conventional compaction. The increased density results in increased tensile properties. For conventional compaction tensile strength is in the range of 1060-1160 MPa. By warm compaction this range can be increased to 1190-1260

MPa. A plane bending fatigue strength of 447 MPa can be achieved with Astaloy CrA with 2%Ni and 0,6 % C by utilizing warm compaction in combination with sinter hardening. These high mechanical properties make the pre-alloyed Cr materials suitable for new high performance applications like synchronizing components, crown clutches, sprockets, cam lobes and others.

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