Cr materials a Means to Lift Mechanical Properties to Next Level, Enabling New Challenging Applications

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Abstract - The continued expansion of the PM market into new applications requires cost-effective materials with increased performance. This can be achieved by different means. The development of new-cost effective alloy systems, new compaction techniques enabling higher densities, sintering combined with increased cooling rates and carbon control are all examples of means that either singly or in combination can be used to increase material performance. Alloying elements commonly used in PM materials intended for high performance applications are copper, nickel and molybdenum. However, raw material prices of these elements have been volatile in recent years, making material cost predictions difficult.

Chromium is interesting as an alloying element due to its performance enhancing ability and cost effectiveness. Cr containing powders in combination with new sintering capabilities regarding both temperature and cooling rates offer means to fully utilize the advantages of Cr as an alloying element enabling cost effective manufacturing of new challenging applications for PM.

The objective of this paper is to demonstrate properties achievable with Cr pre-alloyed powders. After different processing routes, materials based on these powders exhibit properties suitable for synchronizing hubs, cam lobes, gears and other challenging applications.

Key words: Chromium materials, Mechanical properties

INTRODUCTION

Properties of PM steels are today 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 element such as Cr the alloying cost of high strength PM steels can be substantially reduced.

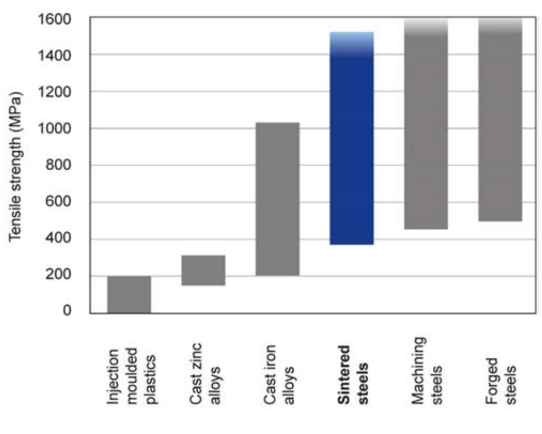

Figure 1. Comparison of tensile strength between PM and other materials

ALLOYING ELEMENTS AND METHODS USED IN PM

During the years lots of research and development have been carried out to utilize Cr as alloying element in PM. The driving force has been to utilize its hardenability and strengthening effect in combination with its cost effectiveness. However, as Cr is prone to oxidization, the processing conditions for both powder and component manufacturing are more demanding. By utilizing master alloys containing high amount of Cr in combination with high temperature sintering, >1200°C, a number of Cr 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 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 the annealing conditions used are more demanding than for conventional iron powders (2, 3). During the years a number of pre-alloyed Cr materials have been developed. These can all be sintered at normal belt furnace sintering conditions 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 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.

Nowadays there is also a growing awareness of sustainability besides cost on the selection of raw materials and production processes. As most manufacturing methods have an impact on the environment by consuming energy and other resources it is necessary to evaluate and select both material and manufacturing processes that will give least impact on the environment.

LCA COMPARISON BETWEEN COMPONENTS MANUFACTURED IN PM 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 (5).

INJECTION YOKE LCA ANALYSIS

A comparative LCA study was carried out on the injection yoke shown in Figure 2.

Figure 2. 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	Material Utilization	Processing
Steel			
SS2225 25CrMoS4	194 g	68 %	Forging, Machining, Heat treatment
PM			
Astaloy CrM	196 g	97 %	Compaction, Sinter Hardening
Distaloy AE	196 g	97 %	Compaction, Sinter Heat treatment

RESULTS AND DISCUSSION

The result of the analysis is shown in figure 3 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. 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 material, primarily due to the high content of Ni.

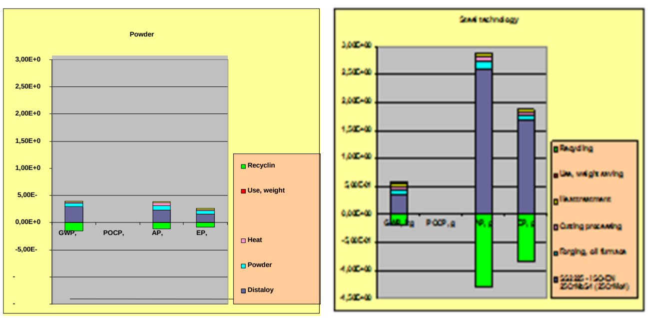

Figure 3. PM (AstaloyCrM) compared to SS 2225

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. The objective of the last part of this paper is to demonstrate properties achievable with 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

Two pre-alloyed Cr-containing materials, Astaloy CrA with 1,8%Cr and Astaloy CrM with 3,0%Cr and 0,5%Mo have been evaluated in this study. 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 (6). 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 7,05 g/cm^3 and for warm compaction about 7,20 g/cm^3..

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. The sinter hardened specimens were tempered at 200^{0}C for 60 minutes in air for stress relief. High temperature sintering trials were done in batch furnaces at 1250°C for 30 min in a 90/10 N_2/H_2 atmosphere. 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.

RESULTS OF SINTER HARDENED CR MATERIALS

Both 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 , figure 4.

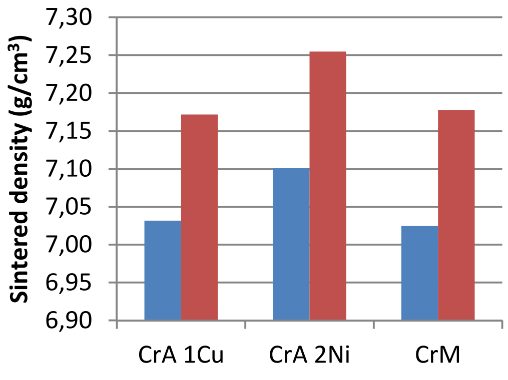

Figure 4. Sintered density and tensile strength for Astaloy CrA with Cu or Ni added and Astaloy CrM in sinter hardened and tempered condition.

The increased density results in increased tensile properties, figure 5. 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 (7).

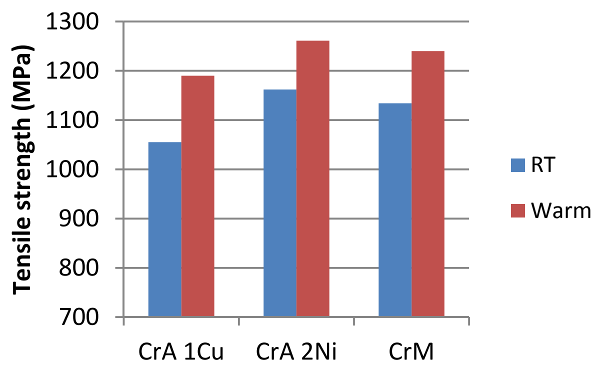

Figure 5. Tensile strength for Astaloy CrA with Cu or Ni added and Astaloy CrM in sinter hardened and tempered condition.

Hardness and fatigue strength follow the same pattern as the tensile strength, figure 6 and 7.

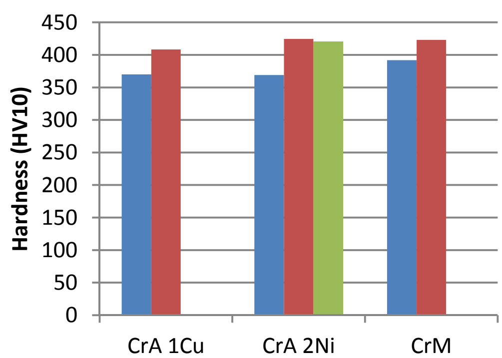

Figure 6.Vickers hardness of conventionally and warm compacted Astaloy CrA with Cu or Ni added and Astaloy CrM in the sinter hardened and tempered condition.

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.

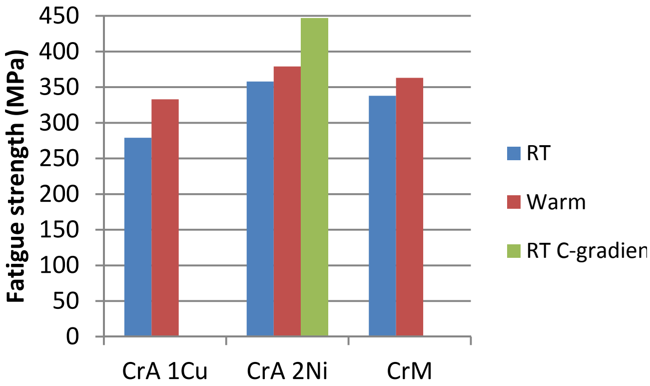

Figure 7. Plane bending fatigue strength of conventionally and warm compacted Astaloy CrA with Cu or Ni added and Astaloy CrM in the sinter hardened and tempered condition.

RESULT OF HIGH TEMPERATURE SINTERING

Mechanical properties after high temperature sintering (HTS) of specimens based on Astaloy CrM-0.5%C and Astaloy CrA-0.8%C are shown in figure 8. Corresponding properties after conventional sintering (CS) at 1120°C are included for comparison. The as-sintered density (SD) is somewhat higher after high temperature sintering (7.16~7.17g/cm^3) than after conventional sintering (7.05~7.06g/cm^3) for both materials. Tensile strength is improved almost 10% for Astaloy CrA while 15% for Astaloy CrM after sintering at higher temperature. Impact energy and elongation are significantly higher after high temperature sintering compared to after conventional sintering for both materials. High temperature sintering improved the sintering neck, promotes pore rounding and shrinkage. The pore rounding effect explains the large improvement in toughness and ductility after sintering at higher temperature.

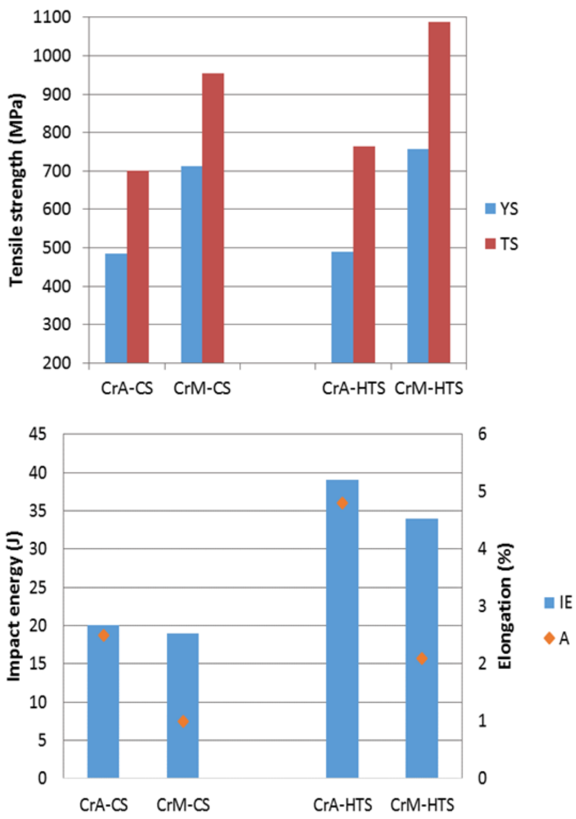

Figure 8. Tensile strength, impact energy and elongation of Astaloy CrA and Astaloy CrM in conventional sintering (CS) and high temperature sintering (HTS) condition.

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.

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. The properties can be further improved by high temperature sintering, especially for toughness and ductility. 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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