GROWTH OF PM THROUGH MATERIAL AND PROCESSES DEVELOPMENT FOR HIGH PERFORMANCE COMPONENTS

Sigurd Berg, Höganäs AB
SE-263 83, Höganäs, Sweden

ABSTRACT

Powder metallurgy (PM) technology has a growth of 7% annually. Competing technologies set demand on the PM technology to convert more highly loaded components to maintain this growth rate. Development work up till today on both material and processes has proven to meet these demands. Chromium as an alloying element has opened up a cost efficient way to manufacture high performance parts. Compacting techniques, sintering concepts and improvements for secondary operations for such a material gives the opportunity for further strengthening of the growth for the PM technology.
In this presentation development trends for high performance components are discussed. Potential for PM technology as such is set in relation towards precision casting and other competitive techniques. Potential material and potential processing techniques are discussed.

INTRODUCTION

Powder metallurgy has a strong growing market. Since most of the parts made by PM are for the automotive industry, cost is a major driving force. Competing technologies like machining, forging, plastics and casting are not standing still in development. For many new PM components final geometry can be reached without the need for machining and the performance comes close to fully dense wrought steel. For the continued growth of PM two main factors are important, close tolerances and high mechanical strength. To meet these, demands development of new advanced metal powders in combination with process development of filling technologies, tooling, presses, sintering furnaces and after treatments. This paper presents performance that can be achieved for high strength PM material by different processes.

PM growth – competing technologies

PM is known as a cost efficient near net shape process for complex parts in large production series. Parts with high tolerances can be produced in the weight range up to 1000 gr. Competing technologies like casting and forging cannot tolerance wise compete with PM. Parts made by plastic can compete regarding tolerances but only for low loaded parts. Machining is a strong competing technology. Increased complexity of the component and/or the material utilization after the machining operation makes PM an attractive technology from a cost point of view compared to machining of wrought steel. The needed number of machining steps is also an important factor.

The powder metallurgy playing field has been identified, ref. JT. The PM playing field is defined in respect of strength and dimensional tolerance, shown in figure 1.

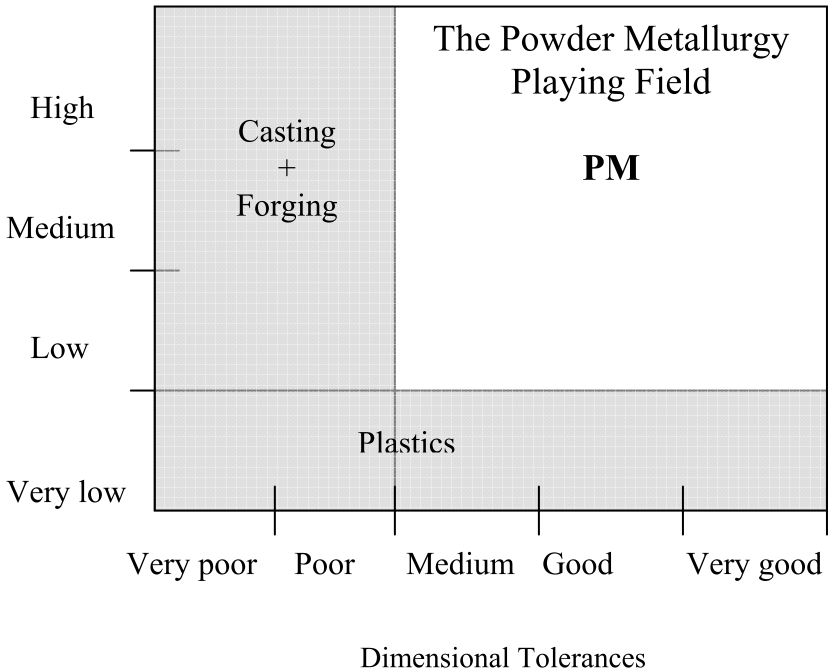


Figure 1. Definition of "Powder Metallurgy Playing Field" related to mechanical strength and dimensional tolerances

If the strength and tolerance demand increases, the competitivness for PM increases and as we can see this sets up a bright future for PM in relation to casting, forging and plastic.
Machining competes strongly with PM. Number of maching steps, the geometry to be machined out, the material utilization and the hardness of part to be machined are criteria for technology selection. Machining cost increases with number of machining steps, complexity of the geometry to be machined out and hardness of the materiall to be machined. Beneficial for the PM technology is the material utilization and that the machining operation can be done in the green stage if demands can be met. Future trend is towards more higly loaded parts which means from the lower left corner to the upper right one. Going in this direction the cost increases at the same time. If the strength demand can be met for complex geomety parts, increased machining can be tolerated for parts produced by the PM technology compared to machinig of wrought steel regarding costs.
As a concequence of this we can state that the growth potential for PM increases by moving up to the right corner.

Materials for the powder metallurgy playing field
Typical material with low strength are alloyed with copper and/or carbon – the work horse for PM. By using the diffusion bonding technique for the copper addition, the dimensinal tolerances are improved. If the graphite is chemically bonded to the base powder further tolerance improvements

are chieved. By adding Nickel, Copper, Molybdenum and graphite the strength is improved. As for the Iron – Copper – Carbon system the tolerances are improved by chemically bonding of the additives. By introducing pre-alloyed material or using the diffusion bonding technique the tolerances are further improved. If high strength properties are needed, additives that during sintering creates a liquid phase can be used. The achieved tolerances after such a process are not to be compared to the ones that are obtained if the diffusion of alloying elements is done in the solid state. Pre-alloyed material and diffusion bonded material based on pre-alloyed base powder is positioned in the upper right corner. Taken the cost into account for alloying elements Chromium has a strong position for the future.

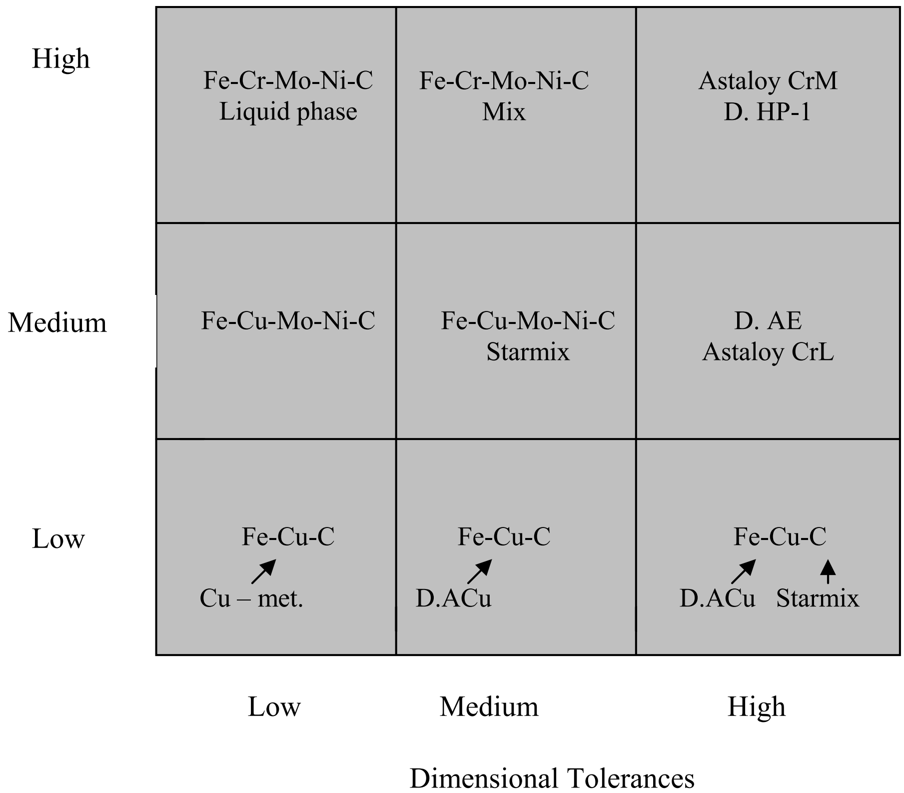


Figure 2. PM material positioned in the PM playing field.

High growth potential for PM by using different processing routes.

Influence of compaction pressure, lubricant and compaction temperature

Density has a major impact on the static and dynamic properties regardless of the used material. Increased compaction pressure enables a high density that improves the properties, figure 3. This opens up for high loaded parts to be produced by the PM technology. Increased compaction pressure is possible as long as free space is available inside the compact. When the theoretical density is approaching, the density increase gets smaller. The slope of the compressibility curve after 58 tsi decreases, figure 4. Multi level parts with complex geometry have limitations in punch length due to bending of the punches at higher compaction pressures. Die and punch material that gives less galling and decrease the friction during compaction of the part are beneficial for an increased playing field for PM.

If the performance of the lubricant allows it, the amount of the lubricant can be decreased. Special designed lubricants like Kenolube are examples of this. Gain in density of 0.1 g/cm^3 is achieved if the lubricant amount is reduced from 0.6% to 0.3%. Temperature plays a role in achieving higher densities. Using the warm compaction technique, an increase in density in the range of 0.15 g/cm^3 to 0.20 g/cm^3 is verified in production of structural PM parts [1]. In reason time heating of the die has been introduced into the market. This technique like the warm compaction technique needs a defined temperature for the lubricant. The gain in density using this technique is ~0.05 g/cm^3. One limitation for this technique is that the powder in the filling shoe needs to reach a uniform temperature before compaction in order to create a homogeneous density within the part. Benefits are stable temperature in the die, which gives improved weight scatter and decreased weight scatter after stop and go sequences.

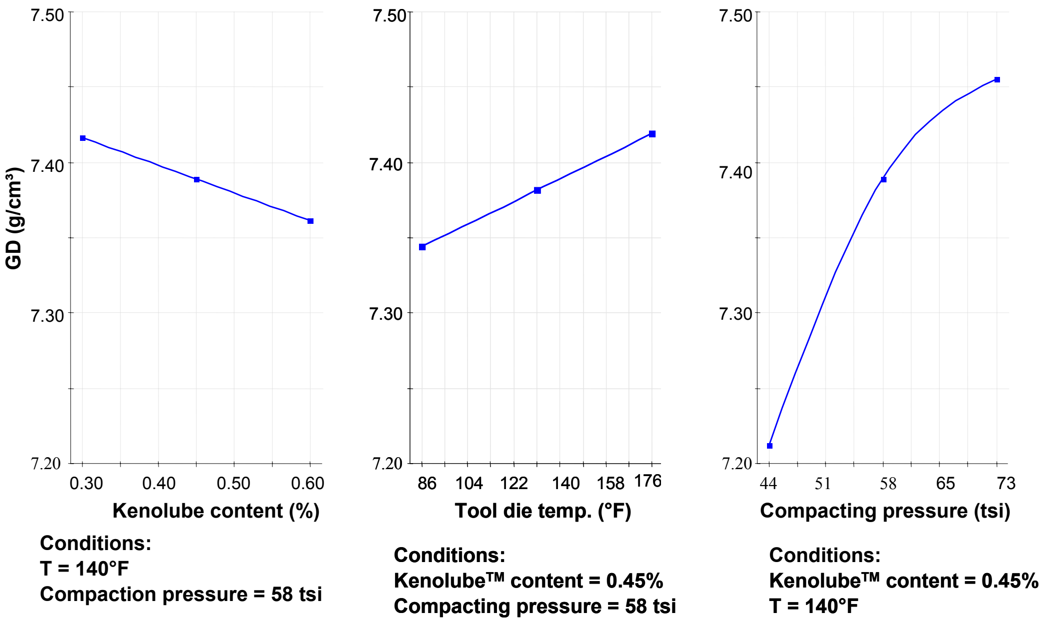
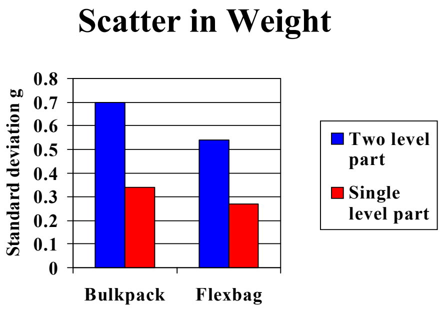


Figure 3. Influence of lubricant amount, die temperature and compaction pressure on the green density for D.AB + 0.3% combined carbon content.

Influence on green weight scatter

To obtain good tolerances, homogeneous distribution and bonding of additives, packaging, filling behaviour and density within the compact are important areas. A good material regarding segregation can be lost during emptying of the package or by bad filling of the cavity. Influence of such a process step should not be neglected in order to obtain better tolerances.

Controlled transportation up and/or down to the filling shoe is essential to maintain a segregation free material. Length and type of transportation equipment introduces mechanical treatment of the material. Achievement in previous processes for improved tolerances can therefore be lost. The configuration of the filling shoe is one of the key factors in control of the tolerances. Gravity or suction filling influence the density within the filled cavity. Finally during the compaction, rearrangement of powder causes weight scatter.



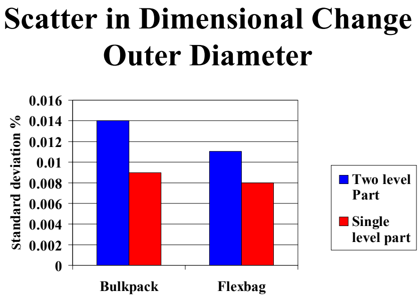


Figure 4. Influence packaging on a single or two level part.

Thermal bonding of metallic additives has been on the market since early seventies. Chemical bonding of smaller/lighter additives like graphite has been introduced at different times. These processes improve the weight scatter and secure that better tolerances can be obtained. In all there is a need to control these steps to maintain the technology that is put into the powder to improve the final weight scatter of the green compact.

Influence of sintering temperature

Increased temperature from 2050°F to 2280°F enhances the sintering activity and therefore the neck growth. High temperature sintering provides more favorable oxidation-reduction equilibrium for alloying elements such as chrome. No oxidation takes place at 1120°C (2050°F) if the oxygen partial pressure of sintering atmosphere is below 5×10^{-18} atm. When sintering is performed at 1210°C (2210°F), the limit of oxygen partial pressure can be raised to 1×10^{-16} atm [2,3].
As a result from high temperature sintering the elongation is increased, figure 5. For a given combined carbon content of 0.35 the gain in elongation is 1%. If the density is increased, in this case by using warm compaction a 1.7% gain is achieved and reaches an elongation level of 4.7%. The mechanical properties obtained are controlled by the microstructure. At a combined carbon content of 0.35% starting at a green density of 7.1 with normal sintering temperature i.e. 2050°C the microstructure is bainitic. Increased sintering temperature to 2280°C or increased density does not increase the strength so much but effects the elongation. This is due to the fact that the material has a bainitic microstructure. The gain in elongation is due to better neck growth obtained by high temperature sintering and increased density. Increased combined carbon content to 0.55% increases the strength and reduces the elongation slightly compared to 0.35%C. A bainitic microstructure determines the properties. High temperature sintering increases the strength, in the same range as compared to 0.35%. By increasing the density a jump in strength is achieved. This is due to a change in microstructure from high temperature bainite to low temperature bainite and martensite. The combined low temperature and martensite gives a tensile strength of 202 ksi and an elongation of 2.9%. The material under these conditions takes hardening i.e more than 50% martensite in the microstructure.

Influence from quenching and tempering
At a combined carbon content of 0.35% after high temperature sintering and warm compaction the tensile strength is 148 ksi and a quench and tempering operation increase it to 229 ksi. This is due to a combination of low temperature bainite and martensite in a good ratio.

Increased carbon content from 0.35% to 0.5% using high temperature sintering and warm compaction the effect from a quench and tempering is only decrease in hardness. This indicates that the amount of martensite has increased and the beneficial effect from a combined microstructure has been lost.

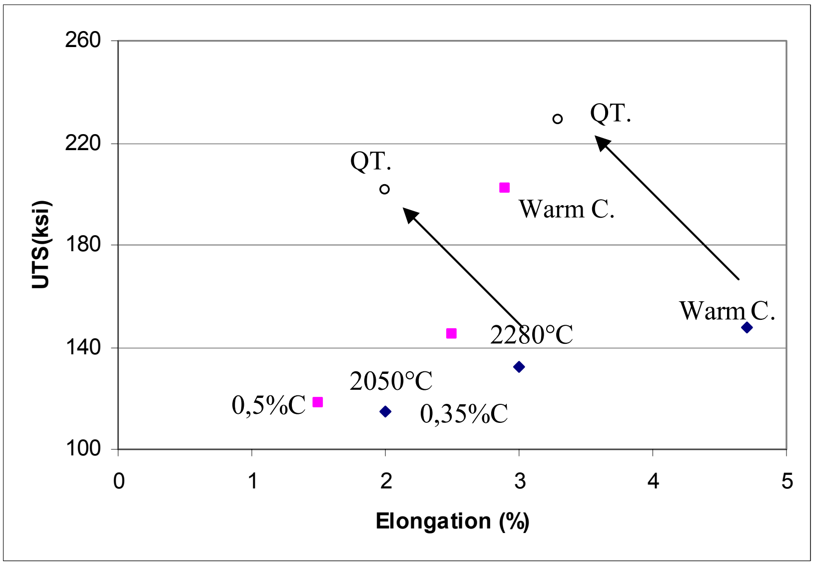


Figure 5. Effect of sintering temperature, increased density and quenched and tempering on Astaloy CrM.

Influence from increased cooling rate - sinterhardening.
Sintering temperature 1120°C

As with conventional PM materials, the properties of Cr-Mo prealloyed materials depend on their density and sintering processes. The results presented in this paper show that Cr-Mo prealloyed materials can provide favorable mechanical properties by selecting a suitable combination of manufacturing processes. Since the properties of PM materials also depend on their compositions, the Cr-Mo prealloyed materials present an excellent alloying system to achieve desired properties. In other words, Cr-Mo prealloyed materials can provide flexibility for material selection to produce medium to high strength structural parts. Figure 6 shows comparisons between the Cr-Mo prealloyed materials and traditional PM materials. Compared to traditional Fe-Cu, Fe-Cu-Ni, and Fe-Ni-Cu-Mo steels, Cr-Mo prealloyed steels can achieve comparable or superior tensile strength but use less alloying content.

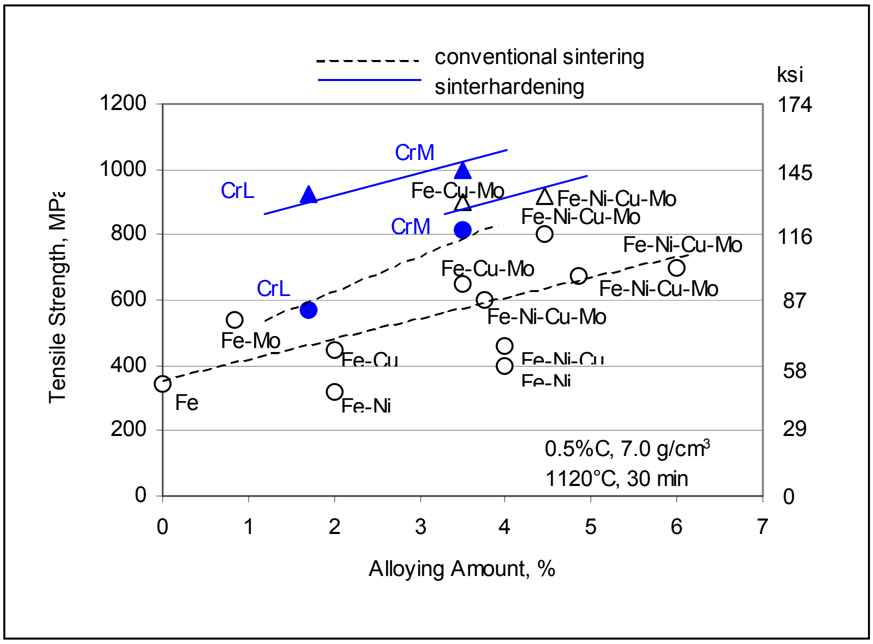


Figure 6. Comparison tensile strength and alloying amount.

Influence of carbon content on tensile strength, figure 7 shows that an optimum can be found at different combined carbon content for each cooling rate. The tensile strength increases with cooling rate. After the maximum is reached the decrease in tensile strength is caused by the amount of retained austenite in the microstructure.

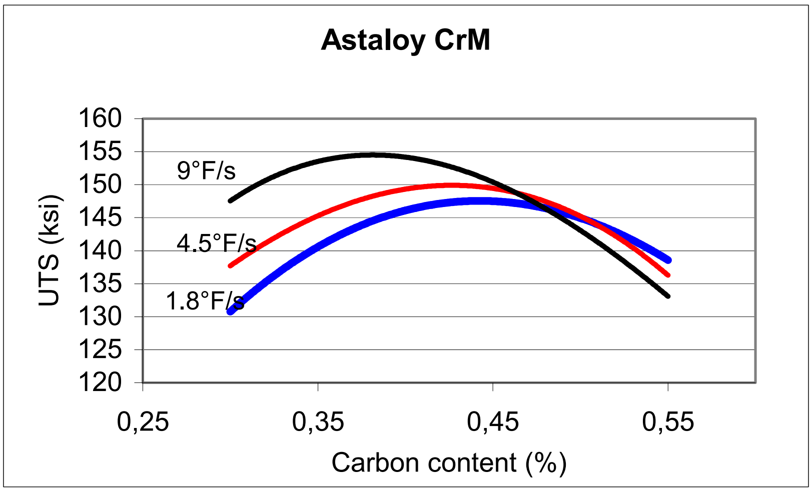
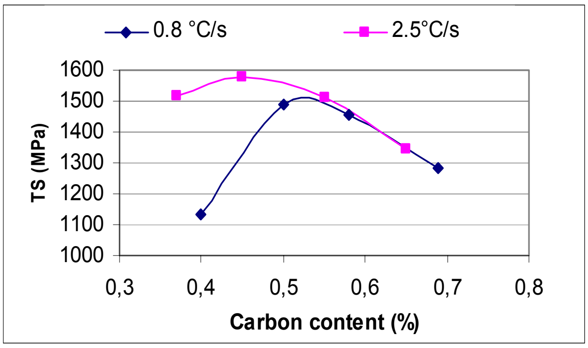


Figure 7. Influence of carbon content

Sintering temperature 2280°C with rapid cooling

Single compaction to a green density of 7.0 g/cm^3 followed by sintering at 2280°C, 30 minutes with and without rapid cooling for a chromium pre alloyed material reaches a final sintered density

of 7.15 g/cm³. A combined carbon content of 0.35 – 0.4% the material do not take hardening. A tensile strength of 1100 MPa is obtained. Increased cooling rate to 2 – 2.5 °C the material takes hardening and 1500 MPa is achieved. For the low cooling rate an optimum in tensile strength can be found at a combined carbon content of 0.55%. The optimum is moved to lower carbon content at higher cooling rates. Decrease in tensile strength is explained by the increased amount of retained austenite in the microstructure.
The dynamical properties, in this case bending fatigue (R=-1) increased with increased combined carbon content. This behaviour is identical to the one for D. AE and D.HP-1.



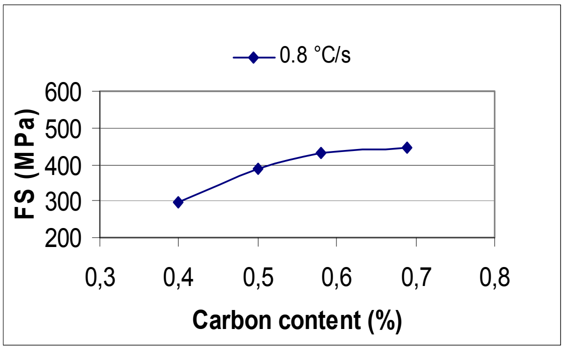


Figure XX

DISCUSSION

Growth for the PM industry is strong and compared to competing technologies has a strong position. This based on the groth compared to competingtchnologies. Increased strength is needed in the future to compete strongly with plastic. Increased density is therefore needed. In the defined PM playing field this means to move up to the right corner where high strength is positioned. In this section of the palyign field tolerances are also high which means that PM can outperforme technologies like casting and forging. Machining of wrought steel compete both tolerance and strength wize with PM. Taken the cost into account PM technology is an strong alternative for complex parts. Develoment of inserts, equipment for machining operation has moved the need for more and more complex part to be made by PM if the cost is the only driving factor. Today the need for more and more operations in order to produce PM parts is the reallity. On the other hand parts that can meet the strenght demand but need heavy machining is an upcomming area for PM.

Chromium as an alloying element sets demand on the PM processing. In the pre-alloyed stage chromium offfers opportunities that enables compitive manufacturing of PM parts compaerd to other technologies. Material and procesing is and will in the future be more and more important to go ahnd in ahnd. That mans that in order to take more market share for PM the combination of right processing together with material optimization must increase. Development work regarding tooling, tool material, PM processes sintering, secondary operations and PM material development is essential to enter this area. Development work has enable the PM industry to compete strongly. For the future, strengthening in selection of material in combination with selection of processing is vital.

CONCLUSIONS

- Improved strength and tolerances are main factors for future growth of PM.
- Increased density by increased compaction pressure, lower lubricant amount, more efficient lubricant , better tooling sophisticated compaction presses, controlled shrinkage is essential for PM growth.

- Cr-Mo prealloyed steels achieve comparable or superior tensile strength using less alloying content compare to other traditionally PM material.
- Rapid cooling and high sintering temperature of prealloyed chromium material has strength above 200 ksi and a bending fatigue up to 65 ksi.
- PM material selection combined with processing is essential for future growth of PM

REFERENCES

[1] U. Engstrom, "High performance PM materials by warm compaction", *Advances in Powder Metallurgy & Particulate Materials*, MPIF, 1998

[2] J. Avidsson and O. Eriksson, "On-Line Measurement of Sintering Atmospheres", *Proceedings 1998 Powder Metallurgy World Congress*, Vol. 2, pp.253~260

[3] Y. Yu, "Thermodynamic and Kinetic Behaviors of Astaloy CrM", *Proceedings 2000 Powder Metallurgy World Congress*