Material and Process Optimization for a Small Engine PM Connecting Rod

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ABSTRACT

Powder metallurgy is known to be a cost-effective technology for manufacturing components with narrow tolerances as well as the required mechanical properties. The selection of the material and process that gives the best cost/performance ratio is a very important factor in becoming the preferred technology to fulfil the requirements of an application. Sintering, sinter hardening with carbon control and different heat treatment operations is all processes of prime interest from this point of view.

This paper evaluates the influence of both the material and process conditions used to produce a small engine connecting rod. A range of materials processed by different methods are compared regarding static and dynamic performance, tolerances and cost for each process condition.

INTRODUCTION

Powder metallurgy is a strong, growing market. Since most of the parts made by PM are for the automotive industry, cost is a major driving force. In recent years new processing techniques and alloying systems have been developed in order to increase the cost/performance ratio. 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.

EXPERIMENTAL PROCEDURES

The mixes used in this investigation are based on three different base powders. The chemical composition of the mixes are shown in table 2.

Table 1. The chemical composition of the adopted powder mixes.

Mix code	Base powder	Ni (%)	Mo (%)	Cr (%)	Cu (%)	Graphite (%)
FeCuC	ASC100.29				2*	0.2
Distaloy AQ	Distaloy AQ	0,5**	0.5**			0.6
Distaloy AQ	Distaloy AQ	0,5**	0.5**			0.2
CrA	Astaloy CrA	2***		1.8***		0.6

* Admixed, ** Diffusion bonded, *** Pre-alloyed

All mixes contained added 0.8% Amide Wax as a lubricant. The graphite used was F10 and Cu-100 mesh with Cu > 98.5% and oxyge < 0,4% was used.

Mixing

Powder mixes were blended according to above amount in a 250 kg nauta mixer. Sieved for oversize particles and packed in 25kg drums.

Compaction

Specimens according to the ISO standard for static and dynamic properties were compacted at 700 MPa using a 140-ton Result hydraulic press. A connecting rod was compacted at 700 MPa in a 400-ton Lauffer press. Dimension for the connecting rod as green is total length of 82,25mm and a center distance of 58,60mm at half of the height for the connecting rod.

Sintering

Specimens were sintered at 1120°C for 30 minutes in a mesh belt furnace with 90%N_2 and 10%H_2 with 0.2% methane addition. Sintering atmosphere were controled by measuring the dewpoint, and

partial pressure of oxygen. Dew point was < -28°C and a partial pressure of oxygen of $< 5.5*10^{-18}$ atm.

Sinter hardening

CrA was sintered using the same settings as for the sintering investigation, but using rapid cooling unit with a cooling rate of 3-5°C/s. Rapid cooling is obtained by increasing the gas velocity and cooling down the gas in the cooling zone. Carbon potential was set by 0.2% methane addition to the sintering atmosphere.

CrA material was also investigated using pure N_2 with addition of natural gas to obtain a CO content of 0.1%. This was done to create a carbon gradient in the specimens and con rods. The cooling rate was set to 3-5°C/s.

All sinter hardened specimens and con rods were tempered at 200°C for 60 minutes in air.

Heat treatment

Through hardening was done on Distaloy AQ at 860°C for 20 minutes with a carbon potental of 0.6%, followed by tempering at 200°C in air for 60 minutes.

Case hardening was done on Distaloy AQ at 860°C for 20 minutes with a carbon potental of 0.8%, followed by tempering at 200°C in air for 60 minutes.

Tolerances

Connectingon rods were compacted in a 400-ton Lauffer press. At least 500 con rods were compacted for each material. Dimensions were measured on 50 con roads, taking out 5 after each 50 compacted. Measurements were done after each investigated process step in a coordination rig, ZEISS Duramax.

Fatigue investigation

Four-point bending fatigue tests were performed for as compacted, un-notched ISO 3928 test bars, modified with a chamfer. The following test parameters were used: load ratio R =-1; frequency: 25-29 Hz; broken specimens stopped after 2.5% increased compliance; run out at 2 million cycles; fatigue endurance [σA,50%] and standard deviation were determined by the staircase method according to MPIF Standard 56..

RESULTS

Mechanical properties

Table 2 shows sintered, sinter hardened and heat treated properties according to standards for GD ISO3927, bars for evaluation ISO 2740, method for testing according to ISO 6892-1, carbon ISO 7625 and hardness ISO 4498.

Table 2, Mechanical properties

	Mix code	GD	SD	TS	YS	HV10	Elong.	C
		g/cm^3	g/cm^3	MPa	MPa		%	%
Sintering	FeCuC	7,21	7.15	555	392	160	2,3	0.58
	Distaloy AQ	7,14	7.15	456	333	146	1.7	0.58
	Distaloy AQ	7,19	7.24	357	190	105	8.7	0.17
	CrA	7,07	7.10	859	633	240	1.1	0.54
Sinter hardening carbon control	CrA		7.10	1162	868	369	0.88	0.56
Sinter hardening – carbon gradient	CrA	7,07	7.14	1093	864	421	0.57	0,59
Through hardening	Distaloy AQ		7.16	994	989	380	0.19	0.51
Case Hardened	Distaloy AQ		7.23	1034	942	441	0.34	0.38

In the as-sintered condition, the FeCuC and Distaloy AQ material has a slight decarburization 0.02%C to a carbon content of 0.58%. CrA for pre-alloyed Cr material has a normal decarburization of 0.06% to a carbon content of 0.54%. The decarburization in all material is homogeneous and is set by the initial oxygen content in the base powder and the sensitivity for oxidation by the alloying elements.

Distaloy AQ for case hardening has a carbon content of 0.17% before heat treatment.

Sinter hardening using methane addition for carbon control shows an increase to 0.56% for CrA.
Sinter hardening using natural gas addition to pure N_2 atmosphere shows a carbon content of 0,59%.

Figure 1a to d shows the change in properties obtained by different processes.

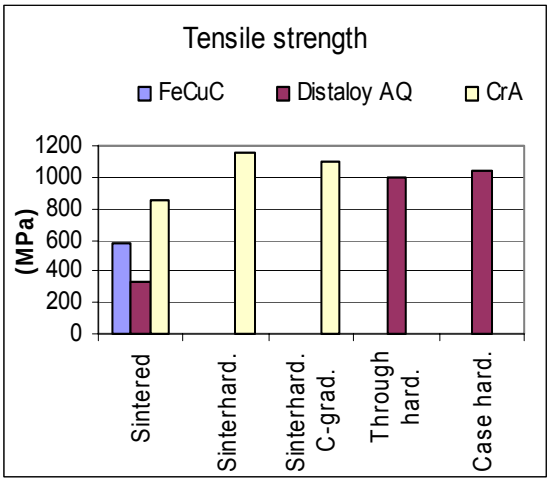


Figure 1a TS vs processes.

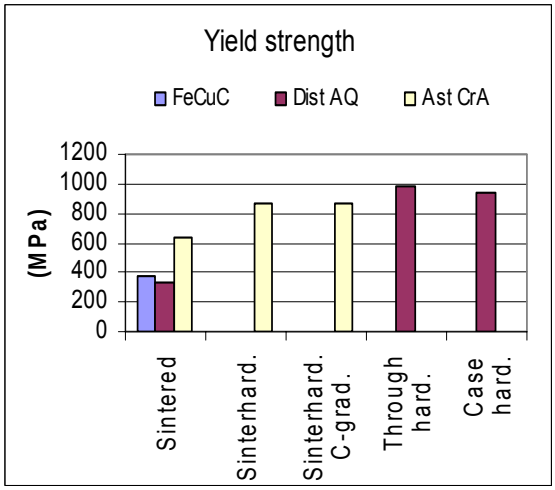


Figure 1b, YS vs processes

The sinter hardening processes give a higher tensile strength compared to the heat treated processes, whereas the yield strength is lower, figure 1a and b.
Hardness for through hardening is close to that achieved by sinter hardening with carbon control.
Case hardening and sinter hardening with carbon gradient achieve a similar hardness, figure 1c.

Elongation for sinter hardening with carbon control (0.88) is higher than for the through hardened one (0.19%), and with carbon gradient sinter hardening the elongation is 0.57% compared to 0.34% for the case hardened one, figure 1d.

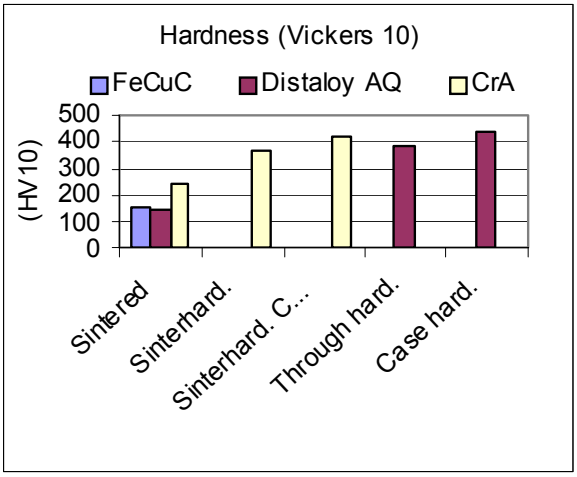


Figure 1c, Hardness vs processes

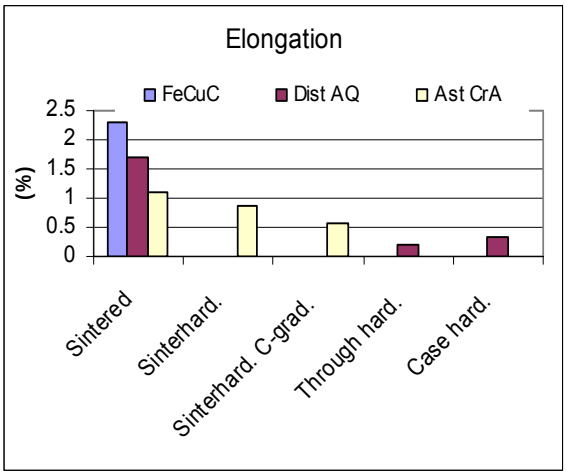


Figure 1d, Elongation vs processes

Dynamic properties
The fatigue strength, σ_{50} at R=-1 for investigated materials in different processes is shown in figure 2. CrA sinter hardened with carbon control has a similar fatigue strength (364MPa) to through hardening Distaloy AQ. Sinter hardened CrA with carbon gradient has slightly higher fatigue strength (447MPa) than conventional case hardening of FeCuC and Distaloy AQ.

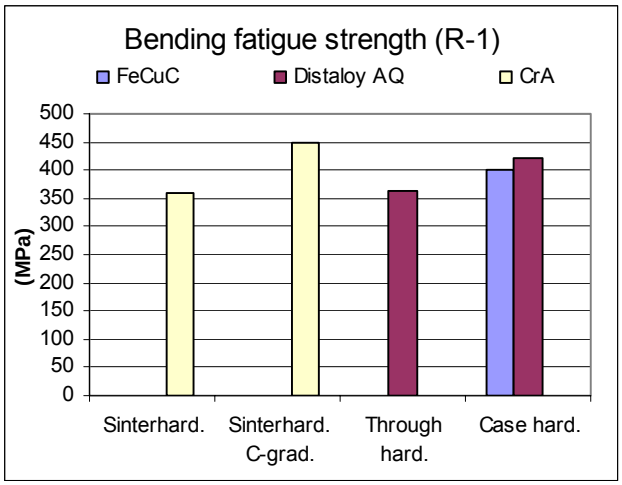


Figure 2. Fatigue strength vs processes

Con rod

Sinter hardened and heat treated con rods were initially tested for axial fatigue at R=-1, figure 3a. Breakage occurred in the predicted area, but not at all times. Fretting occurred on the small end surface, due to the type of fitting on the shaft. This has not been solved at the moment, but the prediction from plane bending fatigue values has shown to be accurate enough to indicate fatigue performance on a small con rod.

Prediction

Results from the stress analysis are shown in figure 3b. The peak stress occurs at the inner radius of the stem at the big end and is σ_{norm}=28.7 MPa/kN

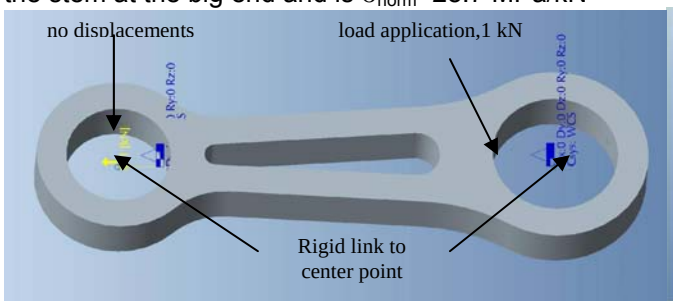


Figure 3a, Model for stress analysis

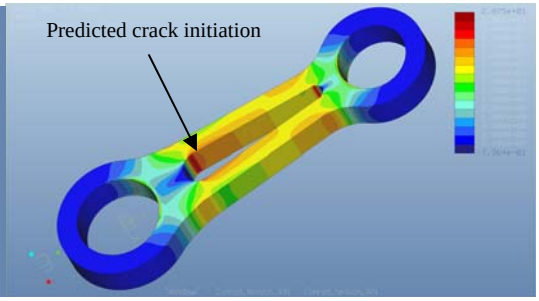


Figure 3b, Results from stress analysis with 1 kN axial unit load.

Calculated fatigue strength values are shown in table 3.

Mix Code	Process	Fatigue strength (kN)
FeCuC	Case hardening.	12.2
Distaloy AQ	Case hardening.	12.8
CrA	Sinterhard. Carbon gradient.	13.1

As the values are based on plane bending, they follow the same individual positioning.

Tolerances
Tolerances are measured as center distances on the con rod.

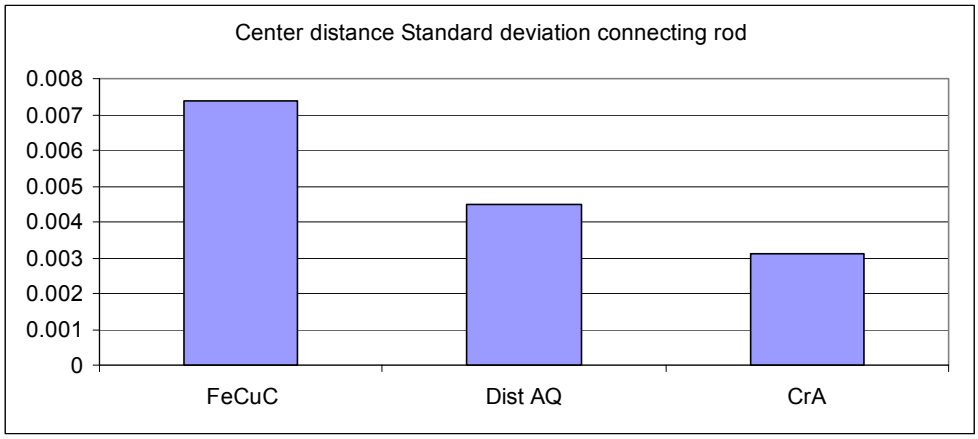


Figure 4, Standard deviation, dimensional change con rod, center distance

FeCuC has the highest scatter followed by Distaloy AQ while CrA has the lowest scatter figure 4.

Cost estimation
The cost estimation is calculated based on production volume of 300kg/hour and assuming that the process will involve; material, sintering or sinter hardening and heat treatment. Compaction and other cost except the one given above are excluded in the comparison. Regarding the sintering process, the influence of atmosphere composition is taken into consideration.

The selected process route for FeCuC and Dist AQ is sintering and heat treatment. The total cost for FeCuC is 3.25EUR/kg and 3.53EUR/kg for Dist AQ.
The selected process route for CrA is sinter hardening. The total cost is 2.11EUR/kg.
Gas composition influence on cost, if it is normalized to 95/5 N_2/H_2 , is for N_2+natural gas=79%, 90/10= 124% and 97/3= 90%.

DISCUSSION

Proposed process routes for the investigated materials are: compaction sintering and heat treatment (through hardening or case hardening) for FeCuC and Distaloy AQ. and compaction and sinter hardening for CrA [1]. The properties for sinter hardening and through hardening show that sinter hardening gives higher elongation, due to the 2% addition of nickel. This, of course, means higher cost for the material as such, but it is possible to eliminate the heat treatment process and thus reduce total cost. The hardenability for the CrA mix can be modified and Ni can be replaced by Cu. Static properties are in the same range, but with reduced elongation to ~0,5%.

The atmosphere used for the sinter hardening process was 90/10 N_2/H_2 with 0.2% methane addition or nitrogen with natural gas addition to obtain 0.10% in CO content. The atmosphere was controlled by measuring carbon CO, CO_2, dew point and O_2. Gases were added through mass flow meters. No active steering of the gas additions were made. Active control of the gas additions is preferable to compensate for leakage or disturbance of the gas flow [2].
Overall gas consumption is 9 Nm^3/h. No soot formation was found in the sintering trials. Methane addition gives carbon control, but no carbon gradient at the surface. Static properties are in the same range for the two used atmospheres with slightly reduced elongation for the natural gas atmosphere, for which a gradient is obtained. This is shown in the fatigue performance of 447 MPA [3] for the nitrogen + natural gas atmosphere compared to 364MPa for the 90/10 N_2/H_2.
This atmosphere composition also offers a cost advantage by a reduction of ~35% in gas consumption cost. Addition of small, controlled amount of oxygen is preferable since the system is easier to control by this addition. The need for pure nitrogen can for this reason be discussed. The natural gas will react with this oxygen and give carbon dioxide to a controlled level.

Alternatives to controlling the sintering atmosphere composition out in the market are offered by furnace manufacturers and gas suppliers, whose understanding of how and where the gas composition is inserted and measured is of prime importance to obtain the carbon gradient on site.

For a small con rod, the material selection has an influence on scatter in dimensions. In this instance pre-alloyed and diffusion bonded material are more suitable. This is seen in the stdev for the centre distance at half of the con rod's height. Note that no bonding techniques for the additives have been used to further improve the tolerances.

Overall it has been shown that sinter hardening compared to heat treatments, such as through hardening and case hardening, is an alternative when it comes to static and dynamic properties. Taking the cost indication into account, the preferred route for the small con rod at this stage is compaction and sinter hardening preferable with gas composition that gives a carbon gradient.

CONCLUSIONS

- Sinter hardening offers the same properties as through and case hardening via different sintering gas compositions
- Carbon gradient improves the fatigue performance by 23%, reaching 447MPa
- Compaction and sinter hardening can eliminate the through hardening and case hardening operation to secure a lower total cost for the con rod
- Sinter hardening using nitrogen with natural gas addition to a CO level of 0.1% creates a carbon gradient without the risk of soot formation
- Highest coat performance ratio is obtained by selection of CrA in a sinter hardening process.

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