High Performance Materials for Sinter Hardening Applications

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ABSTRACT

The development of new materials and cost effective processes are two main factors that have contributed to the growth of PM during the last decades. Sinter hardening, which utilises high performance materials in combination with accelerated post sintering cooling rates, is one example of such material and process development. As this is a one step process it combines good manufacturing economy with the ability to achieve a unique combination of mechanical properties.

However, materials for sinter hardening have been facing increased cost pressure due to the increases and fluctuations in the costs of the most commonly alloying elements molybdenum, nickel and copper. To extend the use of PM into new high performance applications there is a strong need for cost effective alloys that enable enhanced mechanical properties after sinter hardening. In this paper a newly developed cost effective low alloy steel powder containing leaner amount of nickel and copper will be described. Properties achieved after both conventional sintering at 1120 ºC and sinter hardening will be presented.

INTRODUCTION

To continue to expand the PM market into new applications, there is a need for materials with increased performance manufactured in a cost effective way. This can be achieved by different means. Sinter hardening, which utilises high performance materials in combination with accelerated post sintering cooling rates, is one example of such a means. As this is a one step process it combines good manufacturing economy with the ability to achieve a unique combination of mechanical properties.

Alloying elements such as copper, nickel, molybdenum and chromium all promote hardenability and are therefore utilized for sinter hardened PM applications [1,2,3]. However, during the last years there have been a dramatic increases and fluctuations in raw material costs of especially nickel and molybdenum. Therefore there is a continuously growing interest to utilize more cost effective and less volatile alloy systems that enable enhanced mechanical properties after sinter hardening. In this paper some newly developed cost effective low alloy steel powders and their properties achieved after sinter hardening will be presented.

In this paper properties achieved after both conventional sintering and sinter hardening of a newly developed cost effective low alloy steel powder containing leaner amount of nickel and copper will be presented.

EXPERIMENTAL PROCEDURE

The work presented in this paper is based on a newly developed fully pre-alloyed steel powder containing 1,8% Cr with the name Astaloy CrA. To describe the properties that can be achieved with this material under different alloying and processing conditions the work has been divided into two parts. The first one describes properties achievable with Astaloy CrA with different additions of carbon, copper and nickel after conventional sintering. The second part is focused on

properties achievable after sinter hardening of Astaloy CrA with the same alloying additions as described in the first part.

PART 1

Conventional Sintering

Material compositions

Six different premixes with the chemical compositions shown in Table 1 below were prepared. In all mixes 0.60% Intralube E from Höganäs AB was used as lubricant. The graphite used was UF-4 from Krophmühl. Copper was added as a 150 µm powder and Ni was admixed using Inco 123 powder. The designation codes for the different material mixes used in this paper are also described in Table 1.

Table 1. Chemical composition of the powder mixes used

Code used in this paper	Base powder	Cr, %	Cu, %	Ni, %	Graphite, %
A Astaloy	CrA	1.8	-	-	0.4
B Astaloy	CrA	1.8	-	-	0.6
C Astaloy	CrA	1.8	-	-	0.8
D Astaloy	CrA	1.8 1.0		-	0.6
E Astaloy	CrA	1.8 -		1.0	0.6
F Astaloy	CrA	1.8 -		2.0	0.6

Experimental procedure

Tensile strength and impact energy test specimens were compacted of each mix at Höganäs AB in a 125 ton hydraulic press. Different compaction methods and pressures were used in order to obtain sintered density of about 7.0 g/cm^3. The test specimens were subsequently sintered at the conditions outlined in Table 2 below.

Table 2. Sintering conditions

Description Conventio	nal sintering
Furnace type	Mesh belt
Temperature, ºC	1120
Atmosphere, $^{v}/_{0}N_2$ / $^{v}/_{0}H_2$ 90	/10
Time at Temperature. min	30
Cooling rate, ºC/s	0.5

RESULTS OF PART 1

Properties obtained after conventional sintering

In table 3 below the mechanical properties obtained for the different materials are presented. As expected, tensile strength increases both with increased carbon content and the addition of Cu and Ni. For the material without any alloying additions the tensile strength increases about 40% going from 495 MPa at the low carbon content 0.4% C to 700 MPa at 0.8 % C. Yield strength shows corresponding increase of more than 50%. By comparing the tensile and yield strength obtained for the materials alloyed with Cu and Ni respectively to the un-alloyed material with the same carbon content, material B, it can be seen that both

tensile and yield strength are slightly improved. The highest increase is obtained for material F containing 2% Ni. Hardness is also increased by the alloy additions and the highest hardness level is obtained with material F. Elongation is slightly decreased while impact energy is about the same as for the un-alloyed material B. It is interesting to point out the good combination of tensile strength and elongation obtained with material F.

Table 3. Mechanical properties of materials A to F obtained after sintering at 1120°C

Material	Density g/cm^3	Sintered Carbon content, %	Hardness, HV10	Tensile strength MPa	Yield strength, MPa	Elongation, %	Impact energy, J
A 6.98		0.42	140	495	325	3.4	23
B 6.99		0.61	165	610	415	2.8	22
C 7.01		0.80	190	700	500	2.0	18
D 6.98		0.55	175	620	450	2.3	21
E 7.00		0.57	182	641	453	2.2	23
F 7.02		0.61	220	702	489	1.8	22

PART 2

Sinter hardening

Material compositions

Chromium, copper and nickel are elements that all increase hardenability and thereby suppress the pearlite formation during cooling. By combining these alloying elements martensitic microstructures can be formed after sintering at 1120 ºC already at moderate cooling rates, 1.5~2.5ºC/s and proper amounts of carbon.

The same premixes as described in part 1 were used in this study except material A as the carbon content of this material is too low to contribute to any substantial sinter hardening effect. Instead an additional composition, designated G, containing 0.5% graphite instead of 0.6% compared to material F was included. The chemical compositions of the different premixes investigated are shown in Table 4 below.

Table 4 Chemical composition of the powder mixes used

Code used in this paper	Base powder	Cr, %	Cu, %	Ni, %	Graphite, %
B Astaloy	CrA	1.8	-	-	0.6
C Astaloy	CrA	1.8	-	-	0.8
D Astaloy	CrA	1.8 1.0		-	0.6
E Astaloy	CrA	1.8 -		1.0	0.6
F Astaloy	CrA	1.8 -		2.0	0.6
G Astaloy	CrA	1.8	-	2.0	0.5

Tensile strength and impact energy test specimens were compacted of each mix at Höganäs AB in a 125 ton hydraulic press. Different compaction methods and pressures were used in order to obtain sintered density in the range of 7.0-7.10 g/cm^3. The test specimens were subsequently sinter hardened at a temperature of 1120 ºC using a cooling rate of 2.0 ºC/s as described in Table 5below. The specimens were subsequently stress relieved at 200 °C for 60 min in air.

Table 5 Sinter hardening conditions

Description Sinter	hardening
Furnace type	Mesh belt
Temperature, ºC	1120
Atmosphere, $^{v}/_{0}N_2$ / $^{v}/_{0}H_2$ 90	/10
Time at Temperature. min	30
Cooling rate, ºC/s	2.0

RESULTS OF PART 2-SINTER HARDENING

Table 6 below shows the mechanical properties obtained with the different materials after sinter hardening at 1120 ºC.

Table 6. Mechanical properties of different materials after sinter hardening at 1120°C

Material	Density g/cm^3	Yield strength, MPa	Tensile strength, MPa	Elongation, %	Impact energy, J	Hardness, HV 10
B	7.01	509	698	2.5	22	189
C	7.01	576	767	1.8	18	212
D	6.99	920	1034	0.5	20	402
E	7.05	660	845	1.5	20	242
F	7.05	888	1069	0.6	21	324
G	7.07	911	1125	0.8	20	320

By utilizing sinter hardening the mechanical properties for all materials are increased. Tensile strength increases 10 to 15% for the un-alloyed material B and C based on Astaloy CrA compared to the conventionally sintered materials, 610 to 698 MPa for material B and from 700 to 767 MPa for material C. The yield strength shows similar increases. Elongation is slightly decreased by sinter hardening operation while impact energy is maintained at the same level as obtained with the lower cooling rate. Hardness increases with increasing carbon content going from 165 to 189 for material B. For material C the hardness increases from 190 to 212 when the cooling rate is increased from 0.5ºC/s to 2.0ºC/s.

For the materials alloyed with Cu and Ni respectively the increase in both tensile and yield strength are significantly influenced by sinter hardening. Compared to the strengths levels achieved in Part 1 with the lower cooling rate the tensile strength increased more than 60%. Material D, alloyed with 1% Cu, reached a tensile strength of 1034 MPa, an improvement of more than 65% while the Ni alloyed materials achieved tensile strength levels ranging from 845 MPa for the 1% Ni material up to 1125 MPa for materials F and G containing 2 % Ni. Yield strength increased almost 100% by sinter hardening for corresponding materials. The highest

strength levels were obtained with material G having a slightly lower carbon content than material F.

Elongation after sinter hardening was decreased for both alloyed materials due to the martensite formation but the levels achieved, 0.5% to 0.8 %, are very interesting in combination with the high strength levels. The highest elongation was obtained with material E containing 1%Ni. Impact energy is almost maintained at the same level as obtained with the lower cooling rate.

Hardness, HV10, increased for material D to 402. For material F and G hardness increased to about 320 while material E containing 1 % Ni obtained a hardness of 242.

The results presented above show that the newly developed powder Astaloy CrA is a very interesting base for designing new cost effective high performance low alloyed PM materials. Depending on requirements of the application Astaloy CrA either with only addition of carbon or with additions of Cu or Ni can offer a cost effective solution after conventional sintering or after a sinter hardening operation at 1120 ºC.

CONCLUSIONS

Astaloy CrA is a newly developed Cr containing powder suitable for manufacturing of high performance PM components after sintering at 1120 °C . Depending on carbon content, tensile strength levels from 500 MPa to 700 MPa can be obtained after conventional sintering at 1120 ºC.

By adding Cu or Ni to Astaloy CrA, materials that possess good hardenability and thereby give excellent response to sinter hardening operations can be obtained. Fully martensitic structures can be achieved already at cooling rates of 2.0 ºC/s at a density of 7.0 g/cm^3 . At a sintered carbon content of 0.55% tensile strength higher than 1000 MPa is obtained with 1% Cu addition and more than 1100 MPa can be obtained by a Ni addition of 2%. Hardness levels in the range of 300-400HV10 and elongation in the range 0.5 to 0.8 % can be obtained for both alloyed materials after sinter hardening.

REFERENCES

[1] Berg, S. and Maroli, B. “Properties obtained by chromium-containing material”, Advances in Powder Metallurgy & Particulate Materials, compiled by V. Arnhold, C.-L. Chu, W.F. Jandenska, Jr. and H.I. Sanderow, Metal Powder Industries Federation, Princeton, NJ, 2002, part 8, pp.1-14.

[2] Arvidsson J. and Tryggmo A., “On-line measurement of sintering atmospheres”, Proceedings of the 1998 Powder Metallurgy World Congress & exhibition, Granada Spain, European Powder Metallurgy Association, Shrewsbury, UK, 1998, part 2, 253-260

[3] Engström U., Bergman O., Milligan. D. and Klekovkin A, “Influence of processing conditions on mechanical properties of two chromium alloyed PM steels”, EURO PM2007, EPMA, Toulouse, 2007