A Competitive Sinter-hardening Solution for Industrial Manufacturing

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Sinter hardening of PM components is well known as a cost-effective and feasible alternative to secondary heat treatment. Lots of application progress has been made in recent years. Nickel and molybdenum containing materials are very commonly used for sinter hardening application while increases and fluctuations in prices of nickel and molybdenum make manufacturers facing increased cost pressure. From this point of view, chromium-containing alloys show favourable prices and good hardenability, but limitations of atmosphere type and quality have influenced its wide application. To extend sinter hardening application and enhance competitiveness of PM technology there is a strong need for cost effective alloys combined with robustness. In this paper, we present conventional and newly developed lean alloys including both Ni-Mo and Cr-Mo systems, and their achievable properties and consistency under industrial conditions for typical PM applications.

Keywords: *Sinter hardening, mechanical property, dimensional consistency*

1. Introduction

The developments of new materials and cost effective processes contributed significantly to the growth of PM markets. Sinter-hardening, which utilizes high performance materials in combination with an accelerated post sintering cooling rate, is one of outstanding such developments [1, 2, 3]. As this technique is a single-step process, it enables to achieve excellent mechanical properties with good economy.

Due to its unique characteristics of sinter hardening, the researches of sinter hardening materials have achieved significant progress and many different forms of alloying systems have been developed during the past decades. These alloying systems mainly contain nickel, molybdenum and chromium as pre-alloyed elements because of their good hardenability of PM steels [4]. In these alloying systems, nickel and molybdenum containing materials are most commonly used for sinter hardening while the dramatic increase and fluctuation of nickel and molybdenum prices in recent years make manufactures facing increased cost pressure and uncertainty. On the other hand, chromium-alloyed materials offer a cost effective alternative with sufficient hardenability, but the requirement of atmosphere type and quality affects its wide application. Therefore, there is a continuously strong interest in PM industry in pursuit of more cost effective and less volatile alloy system which enables enhanced mechanical properties after sinter hardening.

In this paper, four types of sinter hardening materials including two newly developed cost effective alloying systems were investigated. The influence of different alloying systems on mechanical properties, microstructure and dimensional consistency under industrial manufacture conditions are presented.

2. Experimental Procedures

2.1 Materials

Based on newly developed cost effective pre-alloyed Cr and Ni-Mo steels with conventional Cr-Mo and Mo steels, four different powder mixes were prepared with a bonded mix technology (Höganäs Starmix). The base powder used were Astaloy CrM, Astaloy CrA, Distaloy DH and Astaloy LH. Astaloy CrM is pre-alloyed powder with 3%Cr and 0.5%Mo while Astaloy CrA is newly developed pre-alloyed powder with 1.8%Cr. Distaloy DH powder is based on the fully pre-alloyed Astaloy Mo containing 1.5%Mo to which 2%Cu was diffusion alloyed. Astaloy LH is also a new pre-alloyed powder with 0.9%Ni and 0.9%Mo. 0.6% organic external lubricant (Höganäs Intralube E) was

added as lubricant in all the mixes. The copper admixed was -200 mesh atomized copper powder, and the graphite used was a nature graphite (Höganäs UF-4). The chemical composition and identification codes of the four mixes are presented in Table 1.

Table 1. Chemical composition of investigated powder mixes

Base powder	Identification Code	Ni %	Mo %	Cr %	Cu %	Graphite %	Lube %
Astaloy CrM	CrM		0.5	3.0		0.5	0.6
Astaloy CrA	CrA			1.8	2.0**	0.8	0.6
Distaloy DH	DH		1.5		2.0*	0.8	0.6
Astaloy LH	LH	0.9	0.9		2.0**	0.8	0.6

*Diffusion bonded ** Admixed

Figure 1 shows the compressibility of the four mixes. Mo pre-alloyed DH and lean Ni-Mo pre-alloyed LH, had similar compressibility and better than that of the two chromium mixes. CrM and CrA had relative similar compressibility at medium to high compaction pressure while there was more graphite and Cu in CrA. However, CrM and CrA still have quite good compressibility and can reach the density of 7.0 g/cm^3 at 600 MPa.

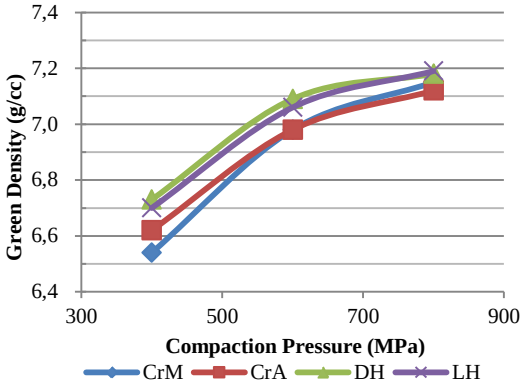


Figure 1. Compressibility of the four mixes

2.2 Sample Preparation and Testing

Green density specimens with diameter of 25 mm and height of 20 mm (ISO 3927) for compressibility measurement were compacted in a hydraulic press at pressure of 400 MPa, 600 MPa and 800 MPa.

Tensile strength test specimens (ISO 2740) and impact energy test specimens (ISO 5747) were compacted to density 7.00 g/cm^3.

Rings of gerotor used in hydrostatic steering as a typical industrial sinter hardening application with outer diameter of 71 mm and height of 24 mm were compacted in a 250 ton industrial mechanical press to a green density of 7.10 g/cm^3. The rings of gerotor compacted for CrM, DH, LH and CrA were about 350 g/pcs and shown in Figure 2.



Figure 2. Ring of gerotor: OD 71 mm and Height 24 mm, ~ 350 g/pcs

All the tensile strength and impact energy test specimens and rings of gerotor were compacted under conventional cold compaction. The sintering of rings was carried out in a 24 inch industrial belt furnace equipped with convection cooling system, and at 1120 ºC for 20 minutes in N_2/decomposed NH_3 atmosphere (93%N_2/ 7%H_2) with net plates. The fan frequency was 30Hz during fast cooling. And then temper was done at 180 ºC for 1.5 h in air. Loading conditions of specimens and rings of gerotor during sintering are illustrated in Figure 3.



(a) Specimens (b) Ring of gerotor

Figure 3. Loading condition of specimens and ring of gerotor during sintering

Compressibility, tensile strength and impact energy were tested according to ISO standards.

Apparent hardness of ring of gerotor was performed

on the both upper (highest distance from belt) and bottom (close to belt) surfaces. Dimension in diameter was also measured based on statistics.

Both tensile test specimens and rings of gerotor were prepared in cross section for metallographic investigation and etched photomicrographs were taken.

3. Results and Discussion

3.1 Mechanical Properties

The comparison of mechanical properties of the test specimens is shown in Table 2. The specimens compacted with CrM reach a sintered density of 6.99 g/cm^3 while others have somewhat lower density possibly due to swelling induced by Cu addition during sintering. The hardness of all materials reached the same level around 41 HRC and only DH is slightly lower. CrM exhibited the higher yield strength, tensile strength and impact energy than those of CrA, but almost no difference in elongation. DH and LH achieved the similar tensile strength, elongation and impact energy each other, while somewhat lower yield strength of LH than DH. CrM and CrA have the lower tensile strength than reference data and it may result from insufficient sintering process and the difference in cooling condition.

With regard to the hardenability of rings, hardness measurement in both upper and bottom surfaces was carried out and result is shown in Table 3. Being the same as specimen test case, CrM parts have somewhat higher sintered density than others. The hardness in CrM, CrA and LH is about 40~44 HRC, while for DH it is around 33 HRC. Upper and bottom surfaces in each material show very little difference in hardness, which indicates the rings were evenly hardened during the fast cooling process.

Table 2. Mechanical properties of specimens

	Sintered density (g/cm^3)	Sintered carbon (%)	Hardness (HRC)	Yield strength (MPa)	Tensile strength (MPa)	Elongation (%)	Impact energy (J)
CrM	6.99	0.48	41	867	896	0.26	16
CrA	6.95	0.76	41	658	684	0.25	11
DH	6.95	0.77	39	770	943	0.50	20
LH	6.96	0.77	41	702	947	0.57	21

Table 3. Sintered density and hardness of rings

	Sintered density (g/cm^3)	Sintered carbon (%)	Hardness of upper side (HRC)	Hardness of bottom side (HRC)
CrM	7.16	0.50	44	43
CrA	7.08	0.77	40	38
DH	7.11	0.78	33	32
LH	7.08	0.76	42	42

3.2 Microstructure

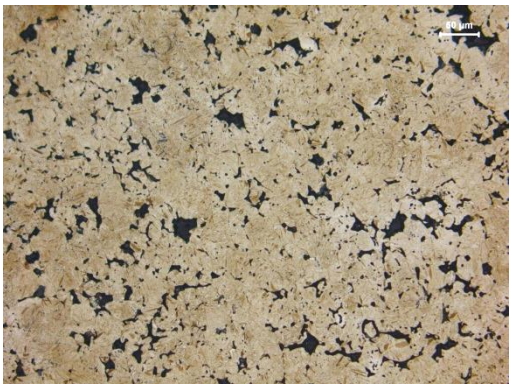
The metallographic investigation of tensile test specimens and rings is shown in Figure 4 and Figure 5.

In the micrographs the bright and yellow regions are martensite, and the dark brown regions are bainite. The martensite volume evaluated from the graphs is presented in Table 4.

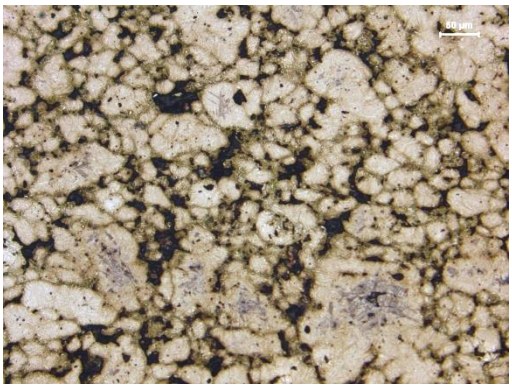
Table 4. Martensite volume in tensile specimens and rings

Martensite%	CrM	CrA	DH	LH
Tensile Specimen	> 99	95	90	99
Ring	98	80	30~40	85

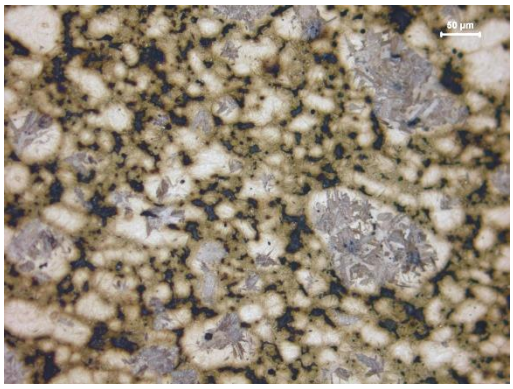
The evaluated cooling rate according to micrographs for tensile specimens was about 1.5 ºC/s while for rings it's around 1 ºC/s. The decrease of cooling rate from tensile specimens should result from much higher mass and more complex shape of rings. The metallography and Table 4 clearly show that high levels of martensite can be obtained at moderate sinter hardening cooling rates (~1.5 ºC/s).



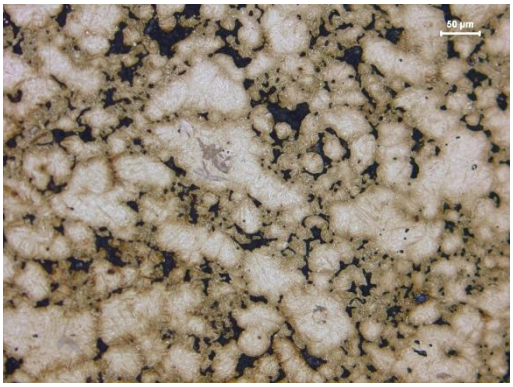
(a) CrM



(b) CrA

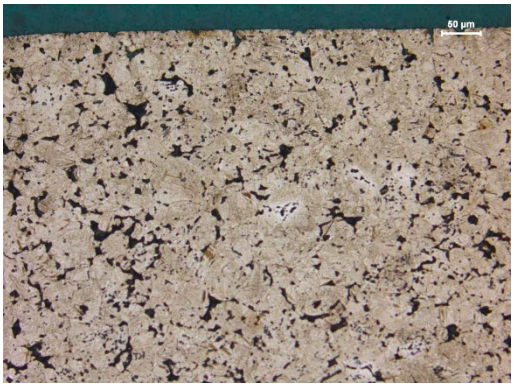


(c) DH



(d) LH

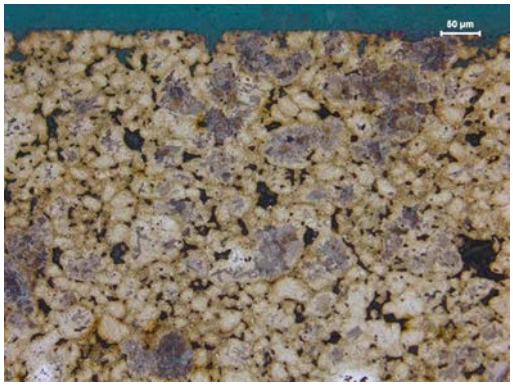
Figure 4. Microstructure of tensile specimens



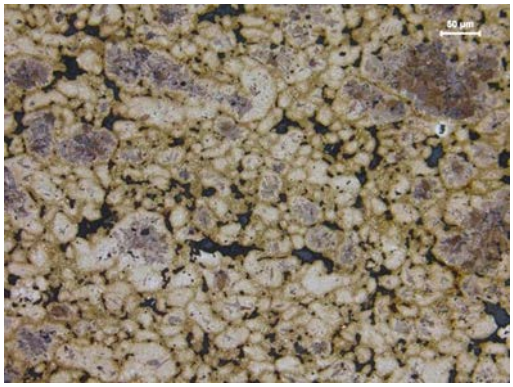
(a) Surface of CrM



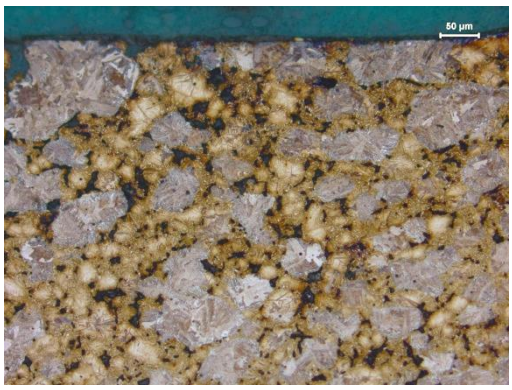
(b) Centre of CrM



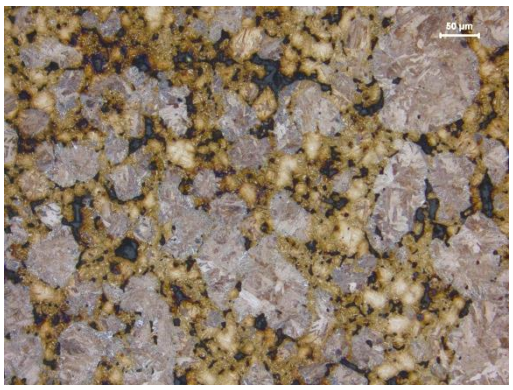
(c) Surface of CrA



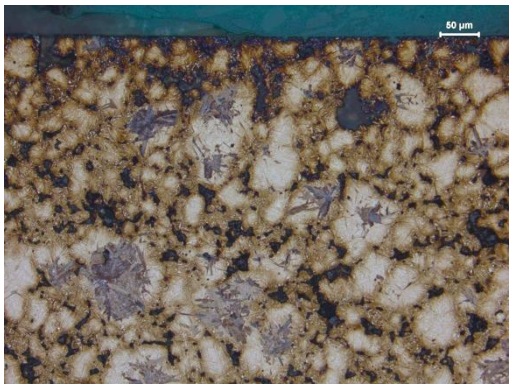
(d) Centre of CrA



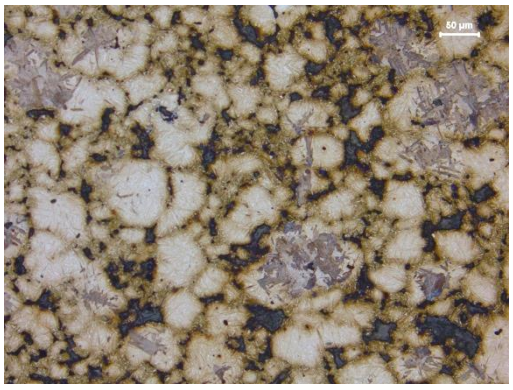
(e) Surface of DH



(f) Centre of DH



(g) Surface of LH



(d) Centre of LH

Figure 5. Microstructure of investigated rings of gerotor

When it backs to ~1 ºC/s in rings, the more high alloyed CrM shows good hardenability almost without loss of martensite and that is why CrM have the highest hardness in rings. Regarding CrA and LH, about 15% martensite was lost from the cooling rate 1.5 ºC/s to 1 ºC/s but the higher hardness especially in bottom surface and somewhat more martensite volume in LH suggest LH has better hardenability than CrA. DH has the relatively worse response to lower cooling rate and lost about 50% martensite, showing lowest hardness.

Regarding low tensile strength in CrM and CrA, there is no obvious abnormity that can be found in metallography, and the tested O and N contents are 0.07% and 0.03% respectively which are quite good. One possible explanation is when checked the temperature profile of the sintering furnace, it's found the heating rate was very low about 0.3 ºC/s from 500 ºC to 800 ºC. In this period, Cr in CrM and CrA could be oxidized due to somewhat worse atmosphere in the positions close to de-waxing zone, and the oxides have a negative effect on sintering necks. These oxides could have been reduced when sintering was finished thus O-level remained in normality. In addition to CrA, some retained austenite in Cu diffusion area should be another reason for its low strength.

3.3 Dimension Consistency in Diameter

Statistic diameter dimension of rings was measured and Figure 6 shows diameter scattering range and standard deviation (STDEV). All the four mixes show excellent consistency after sinter hardening and the diameter scattering range is below 0.03 mm. Especially for CrM which is the best and might because there was no Cu containing in it thus less fluctuation occurred. The high accuracy in dimension control makes less secondary operations possible in high tolerance applications.

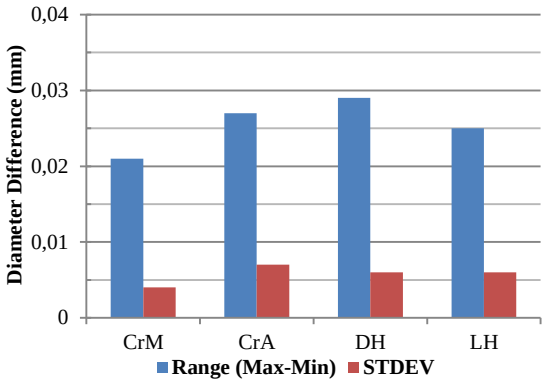


Figure 6. Diameter consistency of rings

4. Conclusions

Four types of sinter hardening materials were tested as commercial parts and standard test specimens. The solution for sinter hardening under industrial conditions can be concluded:

1. Despite of limited cooling rate 1~1.5 ºC/s, high hardness level still can be achieved with all the four materials.
2. Astaloy CrM and Astaloy CrA are the most cost effective sinter hardening materials when relevant sintering process for Cr steel is provided. Especially Astaloy CrM has the best hardenability and robustness.
3. Distaloy DH and Astaloy LH can be sintered in various atmospheres including endothermic gas. When the cooling rate is high enough (1.5~4 ºC/s of typical sinter hardening cooling rate), both are qualified. However, if the cooling rate is low such as 1~1.5 ºC/s due to equipment limitation, Astaloy LH should be the best candidate.
4. These four materials under industrial sinter hardening conditions have excellent dimensional consistency.

Acknowledgement

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