High Performance PM Steels Through Sinter Hardening

Dimitris Chasoglou, Höganäs AB, SE-263 83 Höganäs, Sweden, dimitris.chasoglou@hoganas.com

Abstract

A cost-effective way to achieve high-performance PM low alloyed steel components is the sinter hardening process route. By controlling the cooling rate accordingly one can steer the microstructure and consequently the mechanical performance of the component. Therefore materials with sufficiently high hardenability are required which in turn can be controlled by optimising the chemical composition. In this study a number of materials suitable for sinter hardening applications have been evaluated with regard to their mechanical performance. The study was complemented with basic material data such as CCT diagrams and Jominy hardenability testing. Metallographic investigation was performed in order to correlate the respective microstructure with the obtained mechanical properties. Results show that using the suitable material data one has flexibility in choosing the appropriate material, over a broad range, for addressing challenging applications through the sinter-hardening process route.

Introduction

The continuous strive for manufacturing high performance ferrous PM parts in a cost efficient manner is the key for the expansion of the PM market into new applications. In order to achieve this a number of different actions such as the development of new steel powder grades, improvement of pressing and sintering technology and equipment, secondary heat treatments and operations, can be combined [1]–[3].
The sinter-hardening process is a process combining sintering and hardening operation to one by applying forced cooling in order to increase the harden the part after the sintering zone. Therefore sinter hardening is a cost efficient way to manufacture high-performance PM parts.
To acquire the desired mechanical performance, it is important to tailor the microstructure by optimizing the material composition in relation to the cooling capabilities available after the sintering. The key therefore is to have flexibility in terms of material composition. In order to do that, versatile powder grades are needed where the composition can be adjusted, if needed, by incorporating the proper amount of additional alloying elements in connection with the available processing capabilities in order to match the desired performance [1]–[4]. The latter is becoming more and more important since traditionally used elements such as Ni and Cu, although very attractive in terms of performance, should be used with care due to their issues connected with health and safety as well as from sustainability perspective i.e. Cu has limited recyclability.

Materials and experimental procedure

A broad range of commercially available powder grades has been investigated for the purposes of this study. The focus is put on pre-alloyed grades such as Astaloy CrA (Fe-1.8Cr) and Astaloy CrM (Fe-3Cr-0.5Mo) using also Distaloy DH (Fe-1.5Mo-2Cu) as a reference in terms of microstructural analysis. Ni (INCO 123) and Cu (-100 mesh) was also added in different amounts in blends which had Astaloy CrA as base in order to examine the difference in mechanical properties with the varying alloying content. A summary of the nominal compositions of the prepared blends is shown in Table 1.

	Name	Composition (wt.%)				C (UF4) (%)	Lub HD (%)
		Cr	Mo	Ni	Cu		
1	Astaloy CrA	1.8	-	-	-	0.65	0.5
2	Astaloy CrA+1Cu	1.8	-	-	1 (admixed	0.65	0.5
3	Astaloy CrA+2Cu	1.8	-	-	2 (admixed)	0.65	0.5
4	Astaloy CrA+1Ni	1.8	-	1 * (admixed)	-	0.65	0.5
5	Astaloy CrA+2Ni	1.8	-	2 * (admixed)	-	0.65	0.5
6	Astaloy CrM	3	0.5	-	-	0.5	0.5
7	Distaloy DH	-	1.5	-	2** (Diff. bonded)	0.65	0.5

Table 1. Composition of test mixes.

Using the mixes mentioned above, tensile test bars (ISO 2740) and impact test bars (ISO 5754) were compacted in a hydraulic press using 600MPa pressure. The test bars were sintered in a production furnace at 1120ºC for 30 minutes is a 90/10 N_2/H_2 atmosphere. Different cooling rates from 1.5 ºC/s and up to 5 ºC/s were applied covering also a broad range of cooling capabilities in the furnace systems. Sinter hardened samples were tempered at 200ºC for 1 hr in air for stress relief.

	Name	Green Density ($g \cdot cm^{-3}$)	Cooling rate (ºC/s)		
			1.5	3	5
1	Astaloy CrA	6.99	X	X	X
2	Astaloy CrA+1Cu	7.02	X	X	X
3	Astaloy CrA+2Cu	6.98	X	X	X
4	Astaloy CrA+1Ni	7.01	X	X	X
5	Astaloy CrA+2Ni	6.97	X	X	X
6	Astaloy CrM	6.9	X	X	X
7	Distaloy DH	7.07	X	X	

Table 2. Processing parameters for the materials under investigation.

CCT diagrams were obtained by performing quench dilatometry on cylindrical samples (Ø: 6mm and height: 10mm). The samples were pressed to a density of 6.8-6.9 $g \cdot cm^{-3}$ and sintered at 1120°C for 30 min in an N_2/H_2 – 90/10% atmosphere prior to the dilatometry testing. For the purposes of the test the sintered samples were then induction heated (10°C/s) up to the austenisation temperature (960°C) where they were held for 3 minutes and then were cooled down at different cooling rates ranging from 0.1ºC/s to 200ºC/s using He gas. Metallographic investigation and phase amount estimation followed for all the samples. The CCT curves were generated using the equipment software WinZTU after the phase transformation points were identified from every dilatometry curve.

Results and Discussion

The sintered properties of the tested materials for the different cooling rates applied are presented in Table 3 and in Figure 1. In general, it can be seen that the choice of the suitable material-alloying element combination is greatly dependent on the available cooling capabilities. Addition of Ni in Astaloy CrA leads to slight densification during sintering whereas due to swelling the addition of Cu results in slightly lowered sintered densities for the Astaloy CrA as well as for Distaloy DH. The difference in performance is very similar in the case of adding 1% and 2% Cu in Astaloy CrA whereas the Ni content is affecting the performance in a more severe manner. The cooling rate naturally has very large impact on the attained hardness with the Ni-alloyed Astaloy CrA and Astaloy CrM being the ones affected most.

Material	SD	DC (%)			C (wt.%)			A (%)		
		1.5°C/s	3°C/s	5°C/s	1.5°C/s	3°C/s	5°C/s	1.5°C/s	3°C/s	5°C/s
Ast. CrA	7.02	-0.1	-0.12	0.05	0.56	0.55	0.57	2.3	0.7	0.3
Ast. CrA+1Ni	7.03	-0.18	-0.17	-0.09	0.55	0.57	0.53	0.9	0.5	0.3
Ast. CrA+2Ni	7.01	-0.36	-0.36	-0.14	0.57	0.57	0.56	0.8	0.5	0.3
Ast. CrA+1Cu	6.99	0.01	0.02	0.2	0.53	0.55	0.57	0.5	0.4	0.4
Ast. CrA+2Cu	6.92	0.11	0.12	0.44	0.6	0.62	0.58	0.5	0.3	0.3
Ast. CrM	6.9	-0.18	-0.45	-0.55	0.45	0.46	0.48	0.7	0.6	0.5
Dist. DH	7.02	0.19	0.21	-	0.6	0.59	-	0.9	0.6	-

Table 3. Properties of sinter hardened materials.

The impact energy is greatly affected by the density, and that is why the Astaloy CrA with and without Ni show higher impact energy values in comparison with the Astaloy CrA with Cu additions. The microstructure is also affecting the ductility of the material, and from this perspective the stability of Astaloy CrM in terms of impact energy is noteworthy.

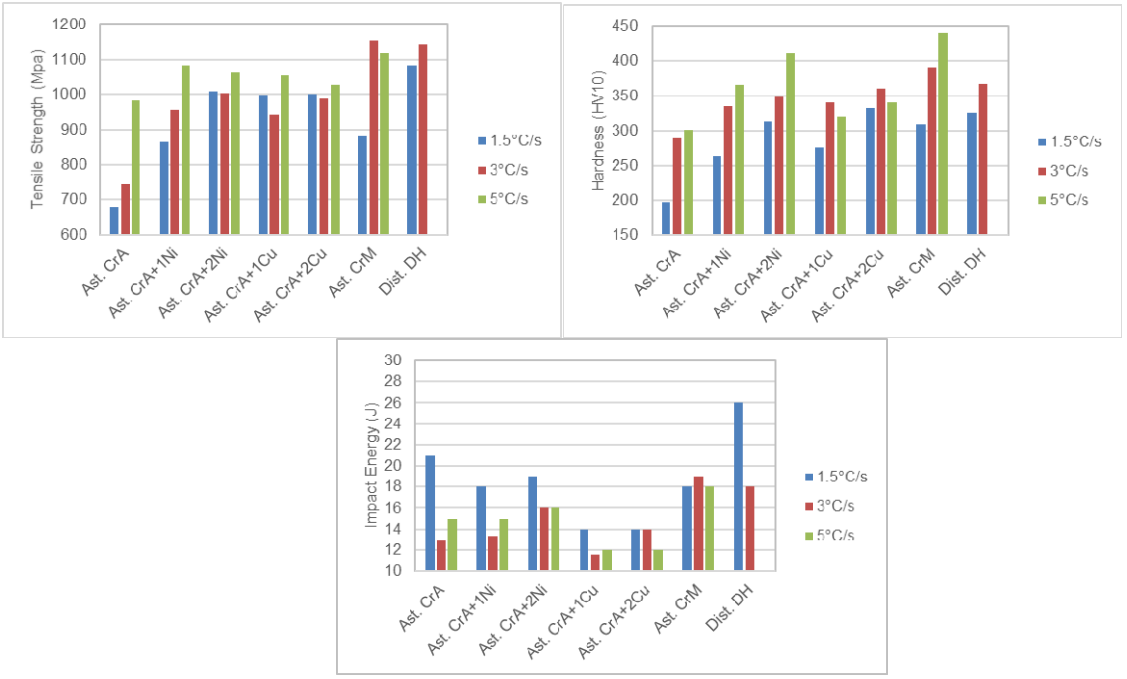


Figure 1. Mechanical properties of sinter hardened materials: Tensile Strength, Hardness and Impact Energy.

A general comment that can be made is that the level of performance for the Astaloy CrA which was admixed with 2% Ni or Cu is very close for all the used cooling rates. Additionally Astaloy CrM which has the lowest sintered density and the lowest C-content has in practice the best sinter hardening response among the compared materials with similar overall alloying content (excluding C, Astaloy CrA+2% Cu or Ni has a total alloying element content of 3.8% whereas Distaloy DH 3.5%).
The above verify the flexibility one can have regarding the mechanical performance of powder grades suitable for sinter hardening depending on the processing conditions available. It has to be pointed out that recent developments in furnace technologies that can enable high temperature sintering followed by

rapid cooling would fully exploit the potential of such grades and reach even higher levels of performance [5]. This will be a result of pore rounding, increased densification and better alloying element dissolution during sintering.

CCT diagrams and metallography

The obtained CCT diagrams for some of the materials mentioned above are shown in Figure 2. The effect of the additional alloying on the hardenability can be seen in the case of Astaloy CrA with and without Ni. In absolute terms, the CCT diagrams show that Astaloy CrM has the best hardenability response.

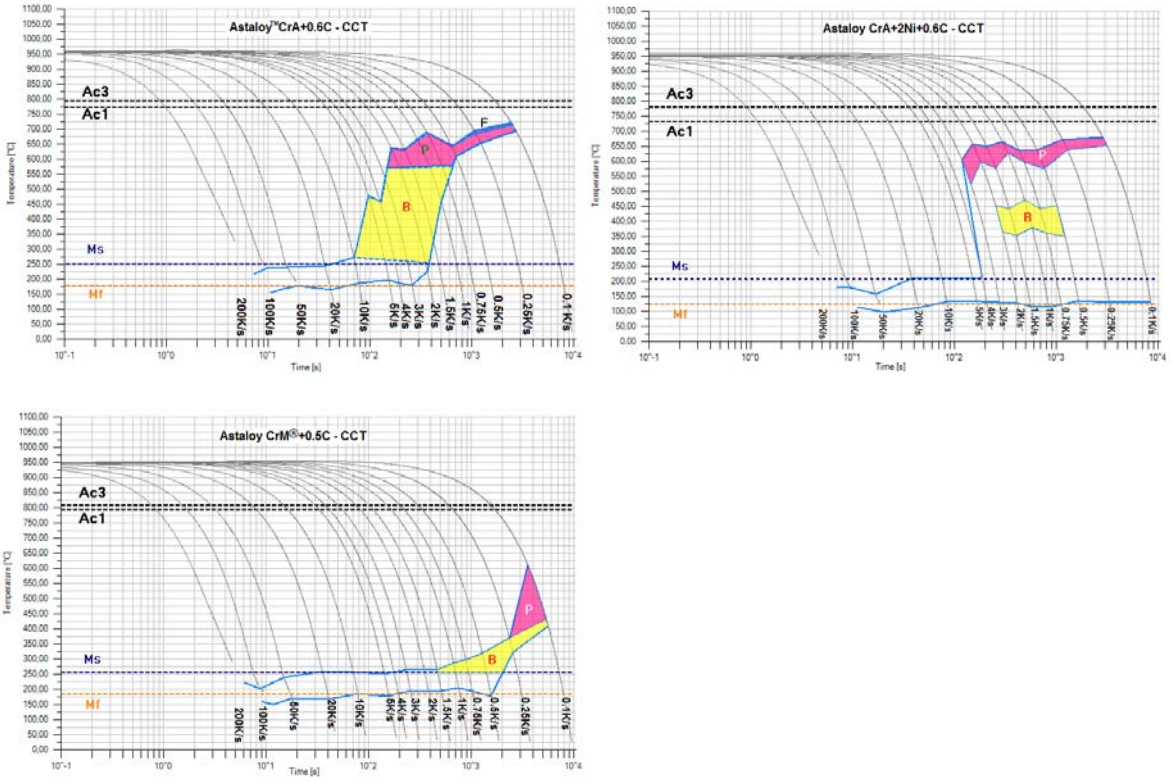


Figure 2. CCT diagrams for Astaloy CrA, Astaloy CrA+2Ni and Astaloy CrM.

The metallographic investigation verifies the CCT diagrams above. For Astaloy CrA cooling down with 1.5°C/s results in a bainitic structure with some pearlite (~20%). With increasing cooling rate the microstructure now is mostly martensitic with some bainite (~20%) present. The addition of Ni (2%) has a drastic effect on the resulting microstructure. Using 1.5°C/s cooling rate the microstructure is already mostly martensitic with some dense bainite and pearlite present. Increasing the cooling rate results in almost a fully martensitic microstructure with some traces of bainite but also some Ni-rich austenite areas (white phase in Figure 4-right). The above are summarized in Figure 5 showing the phase amounts for the microstructures from respective cooling rates.

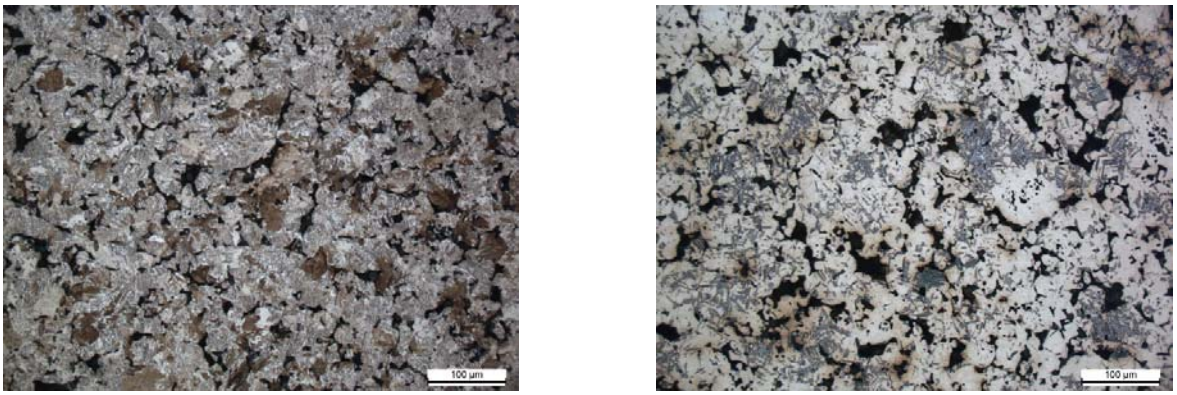


Figure 3. Astaloy CrA cooled down with 1.5°C/s (left) and 5°C/s (right).

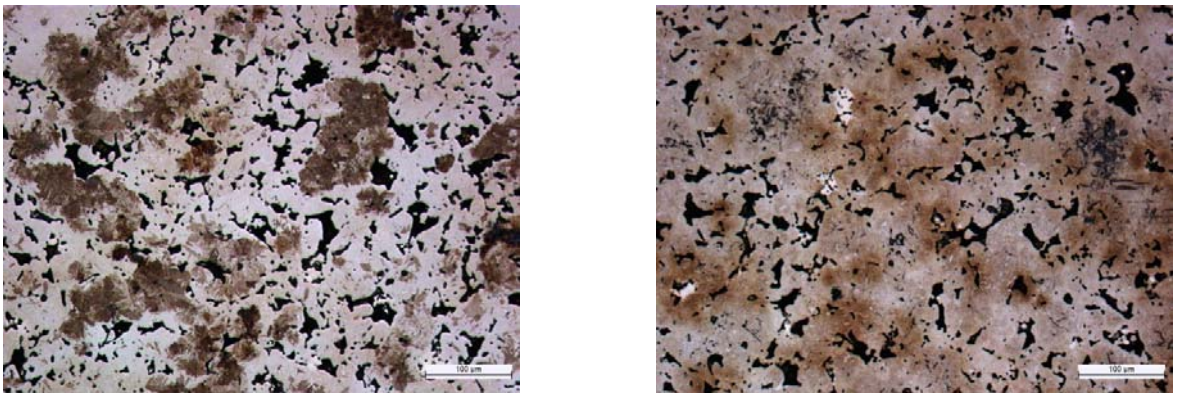


Figure 4. Astaloy CrA+2Ni cooled down with 1.5°C/s (left) and 5°C/s (right).

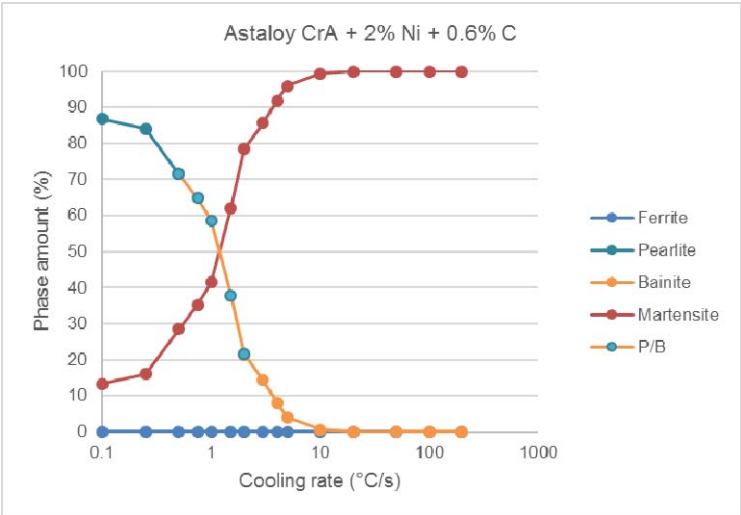


Figure 5. Phase amounts of Astaloy CrA+2Ni from the quench dilatometry testing.

The superior hardenability of Astaloy CrM is also seen in the obtained microstructure, already using a cooling rate of 1.5°C/s results in a martensitic microstructure with some traces (5%) of bainite, Figure 6. The microstructure for Distaloy DH is well documented [6], [7] and was used as a reference in order to

match the microstructures with the used cooling rates. The obtained microstructure is a mixture of bainite and martensite with the amount of martensite increasing with the higher cooling rate.

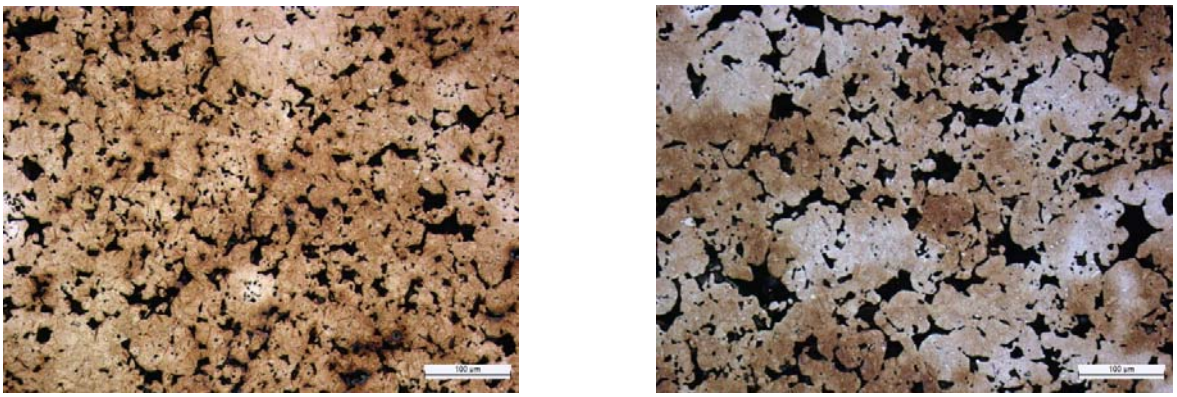


Figure 6. Astaloy CrM cooled down with 1.5°C/s (left) and 5°C/s (right.)

Conclusions

Some key conclusions that can be drawn from this study include:

- The amount of added Ni has larger influence on the mechanical performance of sinter hardened Astaloy CrA in comparison with amount of added Cu.
- The similar amount of overall alloying content, irrespective of the used alloying elements, results in quite similar performance among the materials for sinter hardening applications.
- Additional boost in performance can be achieved with high temperature sintering followed by rapid cooling [5].
- The variety of available materials and the flexibility in alloying is a key for meeting the demands for different applications in connection with pressing, sintering and cooling capabilities available.

References

[1] C. Larsson, U. Engström, and S. Berg, “Means to Lift Mechanical Properties to the Next Level, Enabling New Challenging Applications,” in Euro PM2012 Congress and Exhibition on Powder Metallurgy, 2012, vol. 1, pp. 259-264, PM Improving by Process.

[2] C. Larsson and U. Engström, “High Performance Sinter Hardening Materials for Synchronizing Hubs,” Powder Metallurgy, Vol. 55, No. 2, pp. 88-91, 2012.

[3] U. Engström, C. Larsson, R. Frykholm, “Cost Effective Material for Heat Treated Gear Applications,” in Euro PM2011: Congress and Exhibition on Powder Metallurgy, Sintered Steels: Mechanical Properties.

[4] J. Yang, J. Wang, Y. Han, S. Nim, O. Litström, L. Chen, and W. Feng, “Sinter-Hardening PM Steels with Improved Dimensional Consistency for High Performance Components,” in World PM2014: Powder Metallurgy World Congress & Exhibition, 2014, Part 5 Pre-Sintering & Sintering, pp. 248–257, 2014.

[5] Y. Akiyama, T. Tokuoka, H. Terai, Y. Adachi, and N. Amano, “New Hardening Processes for Transmission Synchronizer Hubs,” in World PM2016: Powder Metallurgy World Congress & Exhibition, 2016. PM Structural Parts

[6] G. Kilic, B. Ögel, and N. Durlu, “Microstructural Investigation of Sinter Hardened Distaloy-DH Powder Alloys,” in Euro PM2013 Congress and Exhibition, 2013, vol. 2, pp.375-380, - Sintering: Atmospheres and Atmosphere Control.

[7] S. Karamchedu, S. Hatami, L. Nyborg, and M. Andersson, “Sinter-Hardening Response of Sintered Steel Based on Astaloy Mo and its Diffusion Bonded Derivatives,” Powder Metall. Prog., 14 (2014)

2, pp. 93-98.