P/M STEEL SUITABLE FOR SINTERHARDENING IN RESPECT OF COST AND PERFORMANCE

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ABSTRACT

Cost reduction for P/M application with maintained mechanical properties is one of the most important factors in order to preserve the strong growth for the P/M industry. Heat treatment has since long time ben used in order to achieve increased properties. By tailor made alloying systems it is possible to include the hardening process. Pre-alloyed material like Astaloy CrM, Astaloy A diffusion bonded alloys as D.DH-1 and premixes based on Astaloy 85 Mo are all suitable for sinterhardening.

In this paper mechanical properties achieved at different cooling rates and carbon contents are discussed. Cost comparison for evaluated materials combined with mechanical properties achievable by the sinterhardening process gives areas for use of these materials. Selection of material is of importance to benefit the most out of this process route.

INTRODUCTION

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

Sinterhardening is of interest due to the cost savings. This process includes the heat treatment process within the sintering process. Knowledge of sinterhardening response for a given composition and condition is necessary in order to keep the cost to a minimum.
Parameters like carbon content, density and amount of alloying elements plays an important role in the selection of powder mix to achieve desired properties. Parameters like austenite grain size i.e large grain boundary area and nucleation sites for perlite formation also influence the hardenability. The selection is to be based on the condition of the sintering process and part i.e knowledge of the cooling rate, part geometry, part size, belt speed and belt loading to gain the most out of this process.

In this paper the effect of cooling rate, carbon content and density on the performance of several materials are evaluated. Cost comparison taken the performance into account is presented.

MATERIAL SELECTION

Theoretical prediction and cost estimation

Theoretical calculation regarding cost and hardenability in order to set suitable composition can be done by calculation of ideal critical diameter and price for alloying elements.
Ideal critical diameter (Di) is the diameter of a cylindrical bar that will form 50% martensite at the center during an ideal quench. The following equation is used:

Di = Dc * F1 * F2 * …….

Dc is the base diameter that depends on the carbon content and the grain size of the material.
F is the multiplying factor for various elements present in the alloy.

Relationship between base diameter, carbon content and grain size is shown in figure 1 [1].
For multiplying factors the amount of nickel must be taken into account due to the effect for multiplying factor of molybdenum, figure 2 [2].

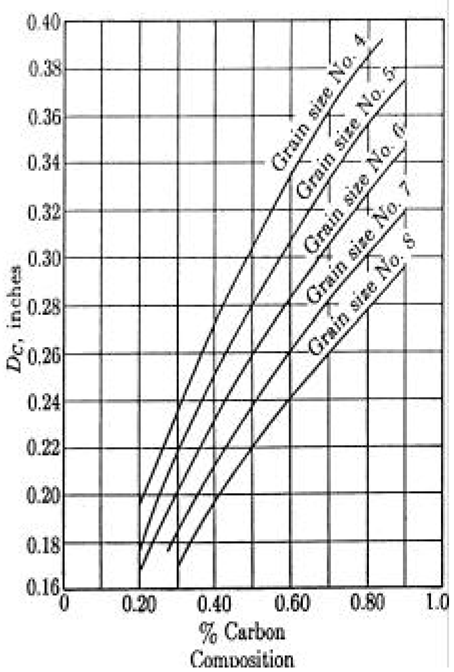


Figure 1. Base diameter,carbon content/grain size

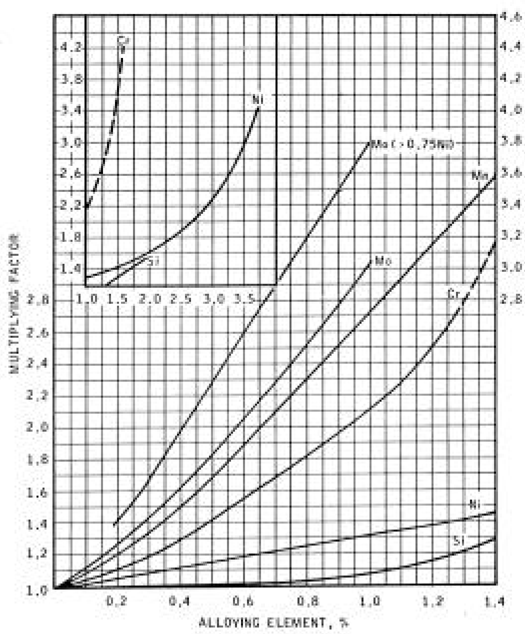


Figure 2. Multiplying factor, element

Addition of copper as premix is known to give a good hardenability. Reported multiplying factors for copper differ much [3]. The amount of copper admixed is equal for all evaluated mixes. A multiplying factor of 1.75 is used in this comparison. Based on this, hardenability and cost are

calculated, table 1. Following assumption is made: Grain size No. 8 at 0.8% C which give a Dc = 0.28 inch. 2% copper is added as premix except for Astaloy CrM.
In the calculation of cost Fe, Ni, Mo, Cr and Mn are taken into account. Cost for alloying elements is taken from supplier. The value is normalised to FLC-4600.
Multiplying factor for material 4 is not possible to obtain see figure 2.

Table 1. Hardenability and cost

Material	**Composition base powder**				**Admixed/ Diffusion bonded***		**Di**	**Cost**
	Ni	**Mo**	**Mn**	**Cr**	**Gr.**	**Cu**		**(%)**
1. Astaloy A FLC-4600	1,9	0,5	0,2		0,8	2	4,60	1,00
2 D.DH-1		1,5			0,8	2*	3,87	0,86
3 Astaloy 85Mo FL-4400		0,85			0,8	2	3,49	0,76
4 Astaloy CrM		0,5		3		-	>10	0,76

It is clear that molybdenum has good response on the hardenability. Iteration exists between nickel and molybdenum (two lines for Mo in figure 2), nickel should therefore be above 0.7% to gain most effect from Mo. It must be mentioned that more interactions can exist. Regarding Mn the amount should be low due to its affinity to oxygen. Chromium is beneficial for hardenability. In this case the activity of chromium must be low in order to prevent oxidation i.e pre-alloyed in low amount is recommended if the sintering is to be carried out at 2050°F.

EXPERIMENTAL PROCEDURE

Materials.
For evaluation four different base powder is used, see table 1. FLC-46000 is a standard sinterhardening grade. D.DH-1 is pre-alloyed with 1.5% molybdenum and diffusion bonded 2% copper. FL-4400 is pre-alloyed 0.85% Molybdenum. Astaloy CrM is pre-alloyed 3% chromium, 0.5% molybdenum. For cold compaction 0.8% Amide Wax was used and for warm compaction Densmix powder with 0.6% lub. Composition of mixes is shown in table 2.

Table 2. Composition of powder mixes

Mtrl. Base powder	Ni (%)	Cu (%)	Mo (%)	Cr (%)	Gr (%)	Lub. % Cold	Lub. % Warm
1. Astaloy A FLC-4600	1,9	2,0	0,5		0,65/0,8	0,8	0,6
2. Astaloy Mo		2,0	1,5		0,65/0,8	0,8	0,6
3. Astaloy 85Mo FL-4400		2,0			0,65/0,8	0,8	0,6
4. Astaloy CrM			0,5	3,0	0,4/0,5	0,8	0,6

Processing condition
For manufacturing of test specimens compacting pressure between 29 to 58 tsi (400 to 800 MPa) was used. The specimens were compacted according to ISO standards using a Tonitechnik 100 ton, semi-automatic laboratory press.

Sintering was carried out in a laboratory belt furnace from Abbot equipped with VARICOOL post sintering cooling system to be able to accelerate the cooling to desired cooling rates. Sintering temperature was 2050°F (1120°C) for 30 minutes at temperature. Atmosphere was a mix of 90% nitrogen and 10 % hydrogen. After sintering tempering at 390°F (200°C) for 60 minutes in air was carried out.

For evaluation of mechanical properties a MTS Sintech 20 D tensile testing machine was used. The gauge length was 1 inch and the speciment were pulled at 1 mm/min. Evaluation of the hardness was performed using the Vickers scale. Prediction in order to cover the broad density interval was done.

RESULT

Density

Evaluation of the sintered density for the materials is shown in figure 3. Cold compaction at 29 and 44 tsi (400 and 600 MPa)

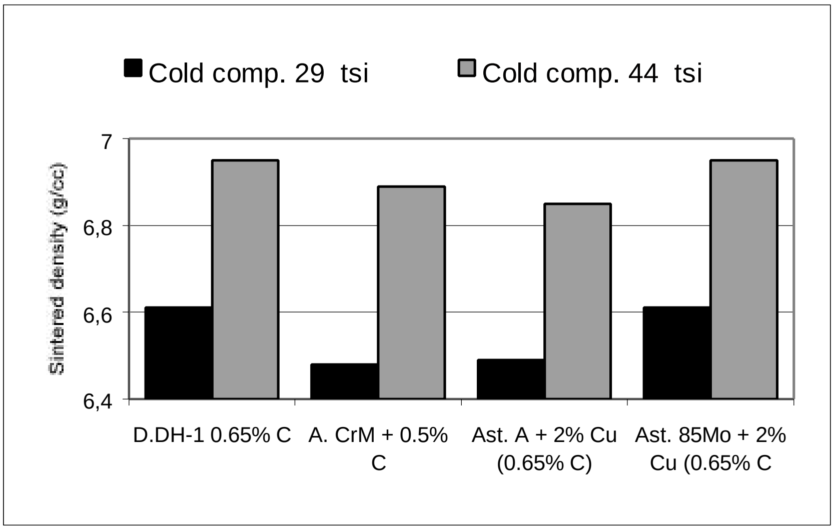


Figure 3. Sintered density, cold compaction.

Two levels can be defined for these four materials. Pre-alloyed molybdenum material achieve a sintered density after cold compaction of ~ 0.1 g/cm^3 higher than Astaloy A and Astaloy CrM.

The dimensional changes obtained at compacting pressure of 44 tsi (600 MPa), cooling rate 4,5°F/s is shown in table 3. The difference in dimensional change for these mixes is large.

Table 3. Dimensional change

Mtrl. Base powder	Cu (%)	Gr (%)	DC (%)
1. Astaloy A FLC-4600	2	0,65	0,29
2. Astaloy Mo	2	0,65	0,29
3. Astaloy 85Mo FL-4400	2	0,65	0,32
4. Astaloy CrM	-	0,5	-0,13

Mechanical properties at different cooling rate and carbon contents

Hardness obtained at a sintered density of 7.0 g/cm^3 is shown in figure 4 for D.DH-1 and Astaloy CrM at different C-contents. For Astaloy CrM only a slight increase in hardness is seen at cooling rates > 4.5°F/s for these rather low C-contents. Hardness for D.DH-1 + 0,65%C increases at all investigated cooling rates. Increased carbon content increases the hardness.

In figure 5 the hardness for Astaloy A+ 2%Cu + 0.65/0.8% C and Astaloy 0.85Mo + 2% Cu + 0.8% C is shown. Astaloy 85 Mo shows the largest increase with increased cooling rate.

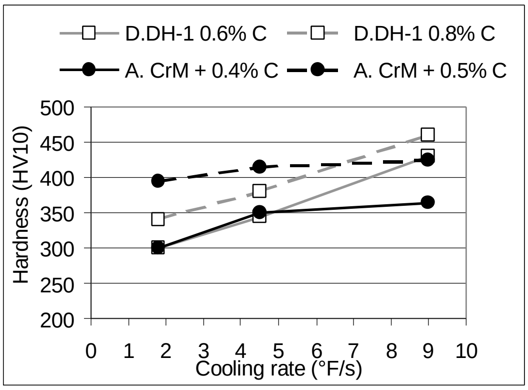


Figure 4, Hardness vs cooling rate

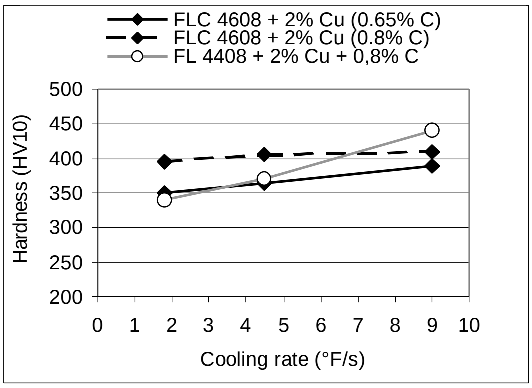


Figure 5. Hardness vs cooling rate

In figure 6 the ultimate tensile strength is shown for D.DH-1 at a sintered density of 7.0 g/cm^3, cooling rates 1.8, 4.5 and 9°F/s. An "optimum" regarding UTS can be defined at a carbon content of 0.6-0,7 %. Increased cooling rate moves this "optimum" to lower carbon contents. In figure 8 UTS for Astaloy CrM is shown, an "optimum" at 0,45% C for the lower cooling rate is seen. Increased cooling rate moves this "optimum" to lower carbon contents.

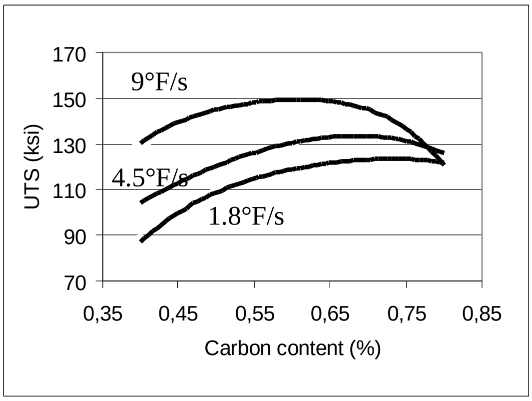


Figure 6. UTS vs cooling rate, D.DH-1

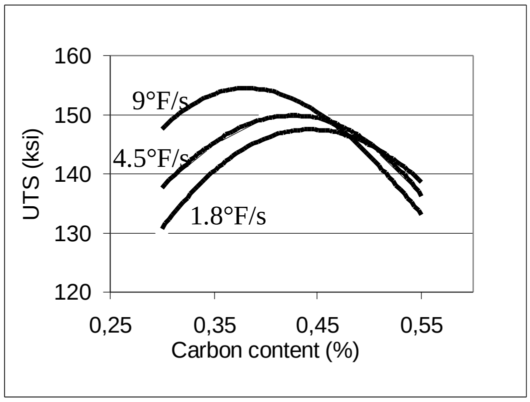
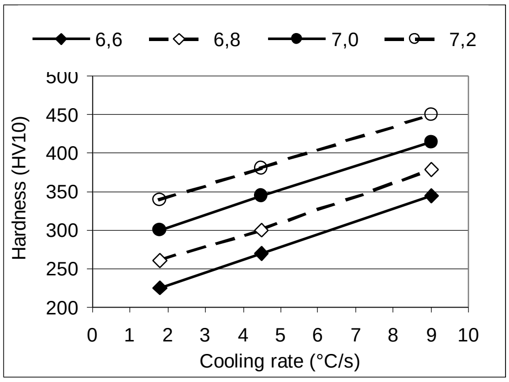


Figure 7. UTS vs cooling rate, Astaloy CrM

Hardness at different cooling rates and sintered densities.

Influence from increased density is for D.DH-1+ 0.65% C and Astaloy A + 2% Cu + 0.6% C seen in figure 8 and 9. Hardness increases by increased cooling rate. No significant difference is seen between the two materials.



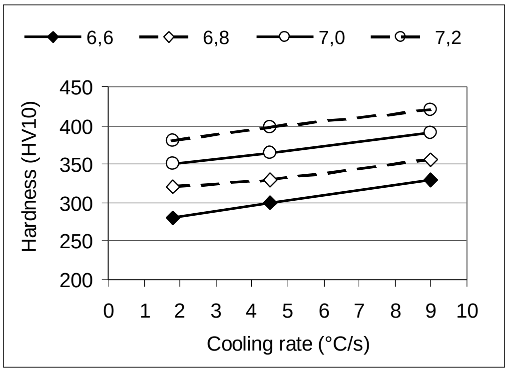


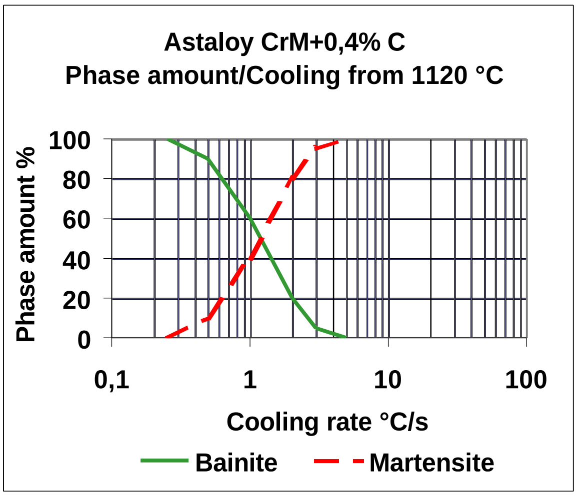
Figure 9. Hardness vs cooling rate D.DH-1 + 0.65% C at 7.0 g/cm^3

Figure 10. Hardness vs cooling rate Astaloy A + 2% Cu +0.65% at 7.0 g/cm^3

Microstructure

Data obtained from dilatometer stydies.

Phase analysis for Astaloy CrM reveals following relation between phases and cooling rate, figure 10 and 11.



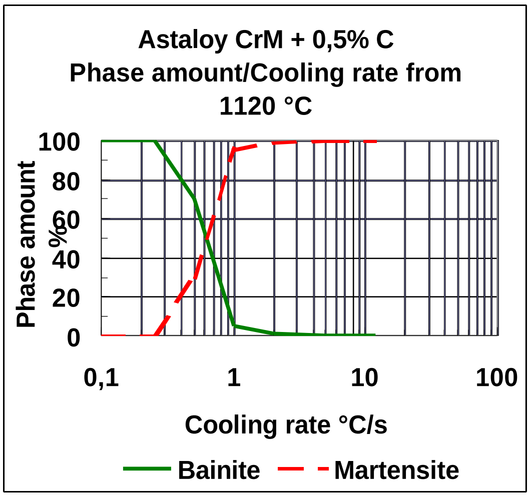


Figure 10 Phase amount, Astaloy CrM + 0.4% C

Figure 11 Phase amount, Astaloy CrM + 0.5% C

In figure 10 the microstructure contains more than 50% martensite at a cooling rate of 2.2°F/s (1.1°C/s). Increased carbon content to 0.5% decreases the necessary cooling rate in order to obtain more than 50% martensite.

The microstructure for Astaloy 0.85Mo + 2% Cu + 0.8% C at a density of 7.0g/cm^3 and a cooling rate of 1.8%°F/s (1°C/s)contains of 55% Bainite and 45% martensite, increased cooling rate to 9°F/s (5°C/s) increases the matrensite content to 99%.

DISCUSSION

To reach desired properties for sinterhardening parts density playes an important role. Compressibility is therefore of prime interest. A factor that improve the hardenability is the total amount of alloying elements. The elements that have good response in hardenability (Mn -> Cr -> Mo -> Cu -> Ni) decrease the compressibility (Cu -> Ni -> Cr -> Mn -> Mo). Molybdenum is the exception, it is therefor the most common alloying element for sinterhardening grades.

In the P/M industry it has almost been a “standard” to admix copper. It has fairly good response in hardenability and as it is admixed it will not decrease the compressibility. Copper is known to cause swelling during sintering this means that the achieved density in the green state decreases during sintering. Performance for D.DC-1 (Astaloy Mo diffusion bonded 2% Ni) regarding sinterhardening is comparible or even exceed the performance to D.DH-1. Higher sintered density is achieved for this material compared to D.DH-1 [4].

Looking at the mechanical properties for sinterhardening grades onen must first decide from the part demand if the aim is to have high hardness or a combination of hardness and mechanical properties. Factors for high hardness is density, carbon content and cooling rate, figure 5,6,9,10. An upper limit in carbon content can be defined caused by the fact of retained austenite formation in the microstructure.

Astaloy A + 2% Cu + 06/0.8% C.
Theoretical hardenability calculation reveals high value, table 1 At a density of 7.0 g/cm^3 and carbon content of 0.8% the hardness is almost constant for different cooling rates, figure 5
This is due to a martensite content of 98%. Looking at the slope for the 0,65% C curve, it increases and is explaind by the transition from bainite to martesite in the structure. The microstructure contains 15% bainite and 85% martensite at 4°F/s.

Astaloy 0.85Mo + 2% Cu + 0.8% C
This is the material with the lowest theoretical hardenability value and the highest slope for the curve, figure 6 Note worthly is that the performance of this material at a cooling rate of 9°F/s (5°C/s) material exceed that of Astaloy A + 2% Cu + 06/0.8% C material.

The amount of pre-alloyed element is low (low cost) and the carbon content is on the upper limit still there is an oppotunity to increase the density in order to move the critical cooling rate down. This indicates that a “lean” composition is possible to use if high sintered density can be achieved (warm compaction) or high cooling rate is possible to obtain. If the part size is small the critical cooling rate is decreased (volume effect). For small part sizes a “lean” composition (FL-4408) is an alternativ.

Astaloy CrM
In the respons in hardness versus cooling rate, figure 5 the slope for 0.45% C mix has a break poinnt between 1.8 (1°C/s) and 4.5°F/s (2.5°C/s). Phase amount is shown in figure 11. At 1.8°F/s (1°C/s) the microstructure contains 45% martensite and 55% bainite. This indicates that the material is taken hardening. Increasing the carbon content lowers the critical cooling rate, figure 12. 50% martensite is obtained at a cooling rate of 0.9°F/s (0,5°C/s). Theoretical hardenability value is not possible to obtain ,even so the hardenability for astaloy CrM is superior to the other materials taken the carbon content and the fact that no copper is admix into account. Increasing the

carbon content hardness levels of 46 HRC is achievedat a sintered density of 6.89 g/cm^3 and a cooling rate of 4,5°F/s (2.5°C/s)

D.DH-1
Theoretical hardenability is between FLC-4608 and FL-4408. Hardness increases both at 0.6 and 0.8% C in the investigated cooling rate intervall, figure5. The microstructure reveals a transition from bainite to martensite (0.6 and 0.8% C) in the investigated cooling rate intervall. 100% martensite is obtained at 9°F/s (5°C/s) for 0.8% carbon.

CONCLUSIONS

- Astaloy CrM takes hardening without copper addion.
- 50% martensite is obtained for Astaloy CrM at cooling rate = 1.9°F/s , (1.1°C/s)
- High hardness levels are achieved for Astaloy CrM at carbon content of 0.6-0-7%.
- "Lean" composition can be used for small part sizes if knowledge about the cooling rate excist.
- Density has a large impact on hardenability.

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