PROPERTIES OF CR-ALLOYED PM MATERIALS

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Abstract
Chromium is an alloying element that is of increasing interest in P/M material. Low cost, recycling advantages and improved hardenability are benefits of using chromium as an alloying element. The combination of good mechanical properties and low alloying cost makes chromium-alloyed materials very competitive.
In this paper, the static and dynamic properties of two materials pre-alloyed with chromium and molybdenum are compared with materials based on more traditional alloying systems for P/M materials, such as Fe-Cu-C and diffusion-alloyed materials. The good hardenability of chromium-alloyed materials also makes this type of material suitable for sinter hardening.

Introduction

Powder metallurgy is a market that is growing strongly. Components produced by the P/M route are replacing components made by competing techniques. One of the major driving forces behind the growth of powder metallurgy is cost reduction. Using chromium as an alloying element is a way to make P/M even more cost competitive compared to competing techniques.

Several alloying techniques are used in P/M materials; blending, diffusion bonding and pre-alloying. Each technique has its advantages and disadvantages. High compressibility can be maintained by blending a pure base iron powder with powders of alloying elements, but the mix is sensitive to segregation of alloying elements, which may cause dimensional scatter of the sintered components.
Diffusion alloying is a technique in which alloying elements of fine particle size are diffusion-bonded to an iron powder, which minimizes the risk of segregation. The impact of the alloying elements is small on compressibility. Finally, alloying elements can be pre-alloyed in the iron powder, i.e. alloying elements are added to the molten iron before atomizing. With this alloying technique, the sintered material achieves a homogeneous distribution of the alloying elements, which is beneficial for the mechanical properties. The drawback is that compressibility is decreased, due to solution hardening of the iron powder particles.

Pre-alloyed materials and hybrid materials that are a combination of pre-alloying and diffusion alloying are increasingly used in the P/M industry. Currently, the most commonly used alloying element in pre-alloyed materials is molybdenum. Molybdenum has the benefits of a relatively small impact on compressibility and that it achieves a good response in hardenability of the sintered material. Chromium as an alloying element has a higher performance/cost ratio, and is therefore of great interest for the future.

Today, copper is one of the most widely used alloying elements for P/M materials. Recycling of materials containing copper is a problem, in contrast to materials containing chromium.

When sintering materials alloyed with chromium, good control of the sintering atmosphere is required due to the high affinity to oxygen of chromium [1, 2]. By pre-alloying the iron

powder, the activity of chromium decreases, which is more beneficial compared to using chromium additives with a higher Cr concentration.

In this paper, the properties of two materials pre-alloyed with chromium and molybdenum, Astaloy CrM (3% Cr and 0.5% Mo) and Astaloy CrL (1.5% Cr and 0.2% Mo), are compared with commonly used alloying systems, FC-0208, FD-0205 and FD-0405.

Astaloy CrM is a high-strength material and will in this paper be compared to FD-0405, which is a diffusion-alloyed material widely used in high-strength applications. Astaloy CrL has a lower amount of alloying elements, is a medium to high-strength material and will be compared to FC-0208 and FD-0205 materials.

Pre-alloyed materials are well suited for sinter hardening, a technique of increasing popularity to obtain high-strength P/M materials. For sinter hardening, a convective cooling unit is used directly after the heating zone of the sintering furnace. Sintering and hardening is thus done in a single operation. Materials pre-alloyed with chromium have a good response to sinter hardening and data on these materials in sinter-hardened state is presented in this paper.

Experimental

Three alloying methods are represented in the materials covered in this paper; pre-alloying, diffusion alloying and admixed alloying elements. The base powders used are presented in table 1.

		Alloying elements			
Base powder	Alloying method	Cr	Cu	Ni	Mo
Astaloy CrM	Pre-alloyed	3.0%			0.5%
Astaloy CrL	Pre-alloyed	1.5%			0.2%
Distaloy AE	Diffusion alloyed		1.5%	4.0%	0.5%
Distaloy AB	Diffusion alloyed		1.5%	1.75%	0.5%
AHC100.29	-				

Table 1: Alloying methods and alloying contents of base powders

Green density of pure base powders was measured according to ISO 3927 with lubricated tool die.

Besides the alloying elements in the base iron powders, graphite, and in some cases copper, are added to the materials, see table 2 for mix compositions. As lubricant 0.8% amide wax was added to all materials. In the comparison of the different alloying systems, an optimum carbon level for each material was chosen in order to have a good combination of strength, ductility and fatigue strength.
One percent copper is added to material C in order to increase hardenability and achieve a good response to sinter hardening. FC-0208 has 2% copper powder and 0.8% graphite admixed, and is one of the most widely used Fe-Cu-C compositions in the P/M industry.

		Alloying elements	
Material	Base powder	Cu	C
Material A	Astaloy CrM		0.45%
Material B	Astaloy CrL		0.75%
Material C	Astaloy CrL	1%	0.6%
FD-0405	Distaloy AE		0.6%
FD-0205	Distaloy AB		0.6%
FC-0208	AHC100.29	2%	0.8%

Table 2: Alloying addition to investigated materials

Values for sintered properties, except fatigue strength, are not taken from single measurements, but are based on a large number of test series, of which the presented values are calculated by statistical methods. The data is also presented more extensively in [3]. Material C is an exception in which sintered properties originate from single series of specimens. The reason is that data from an extensive test plan, as a base for statistical calculations, was not available for material C.

Tensile bars (ISO 2470) and impact energy bars (ISO 3325) were compacted in a Result semiautomatic laboratory press.

Sintering was carried out in laboratory mesh belt furnaces. Specimens of all materials were sintered in 90/10 N_2/H_2 atmosphere at 1120°C for 30 minutes with a cooling rate of ~0.8°C/s. Material A and C were sinter hardened in 90/10 N_2/H_2 atmosphere at 1120°C for 30 minutes with a cooling rate of 2-3°C/s. Sinter hardened materials were tempered at 200°C for 60 minutes in air.

The fatigue tests were performed in instrumented displacement-controlled four-point-bending Schenk machines at a testing frequency of 26-28 Hz. The tests were carried out according to the stair case method with run-outs at 2 million cycles and the evaluation of 90% probability fatigue limits was made according to MPIF standard 56.

Results and discussion

Compressibility of base powders is presented in figure 1. The two diffusion-alloyed base powders Distaloy AB and Distaloy AE obtain best compressibility. AHC100.29 has somewhat lower compressibility. This is explained by the fact that Distaloy AB and Distaloy AE are based on the highly compressible ASC100.29 iron powder grade, with higher purity than AHC100.29. By pre-alloying iron powder with chromium and molybdenum, the compressibility decreases due to solution hardening. This is seen in the compressibility of Astaloy CrL and Astaloy CrM. The latter has the highest amount of alloying elements and consequently the lowest compressibility.

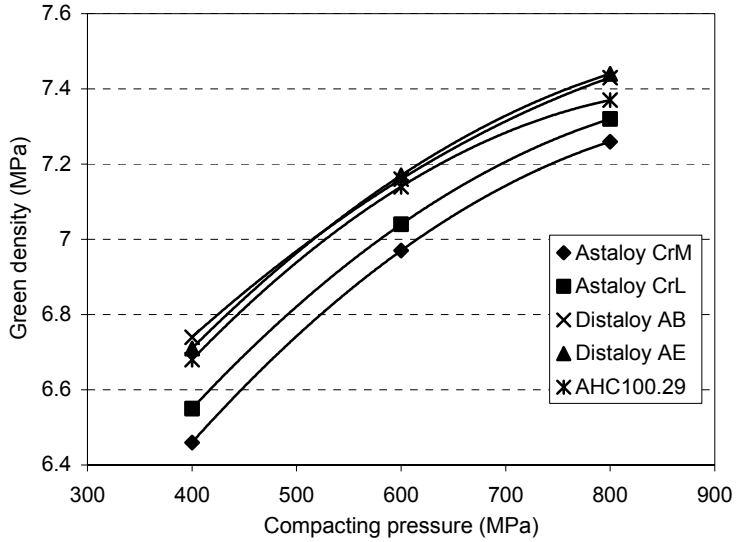


Figure 1: Compressibility of base powders with lubricated tool die

Sintered properties are presented in table 3.

Table 3. Mechanical properties of sintered materials

Material	Compacting pressure MPa	SD g/cm^3	DC %	UTS MPa	YS MPa	HV10	Elong %	IE J	Sintered carbon %
A	600	6.9	-0.21	822	637	275	0.9	18	0.45
A	800	7.1	-0.21	949	716	303	1	22	0.45
A	600	6.9	-0.13	963	896	341	0.3	14	0.45
A	800	7.1	-0.11	1091	998	378	0.3	14	0.45
B	600	6.9	-0.06	739	623	231	1	12	0.75
B	800	7.1	-0.05	826	699	258	1.3	14	0.75
C	600	6.93	0.01*	923	784	298	0.4	13	0.58
C	800	7.09	0.06*	1015	878	363	0.4	15	0.58
FD-0405	480	6.90	-0.20	687	386	227	1.8	19	0.60
FD-0405	620	7.10	-0.17	762	418	247	2.2	26	0.60
FD-0205	500	6.90	-0.05	580	384	184	1.4	17	0.60
FD-0205	650	7.10	-0.04	643	417	204	2.0	23	0.60
FC-0208	540	6.90	0.24	434	342	146	2.1	15	0.80
FC-0208	760	7.10	0.23	472	363	166	2.7	23	0.80

* die to sintered.

Tensile strength and yield strength are presented in figure 2 and 3. As expected, all materials gain in strength, as well as hardness and ductility, from increased density. Highest tensile strength is obtained by material A, followed by material B. Material B is slightly higher in tensile strength than FD-0405. FC-0208 has the lowest tensile strength of the compared materials.

The yield strength of the pre-alloyed materials A and B is more than 50% higher than for the other three materials in the comparison. Material A and B also gain more in yield strength by increasing density from 6.9 to 7.1 g/cm³ compared to the other materials. The yield strength of diffusion-alloyed materials FD-0405 and FD-0205 is low compared to the pre-alloyed

materials, due to the heterogeneous structure, which includes softer phases such as nickel-rich austenite and ferrite.

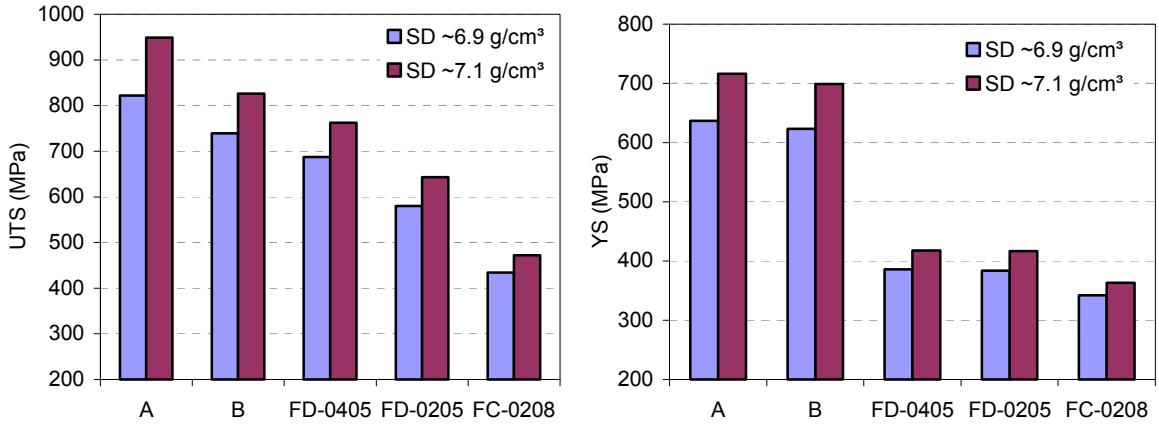


Figure 2 and 3: Tensile and yield strength for sintered materials

The highest hardness is achieved with material A, followed by material B and FD-0405, which have similar hardness when compared at the same density, see figure 4. If the comparison is made at the same compacting pressure, FD-0405 will have somewhat higher hardness than material B.

The structure of diffusion-alloyed materials is beneficial for obtaining a good combination of strength and ductility. The impact energy is higher for FD-0405 than for FC-0208, and this is combined with much higher tensile strength and hardness. Ductility is, in general, lower for pre-alloyed materials.

FD-0405 has higher strength as well as elongation and impact energy compared to FD-0205. This is due to the higher nickel content.

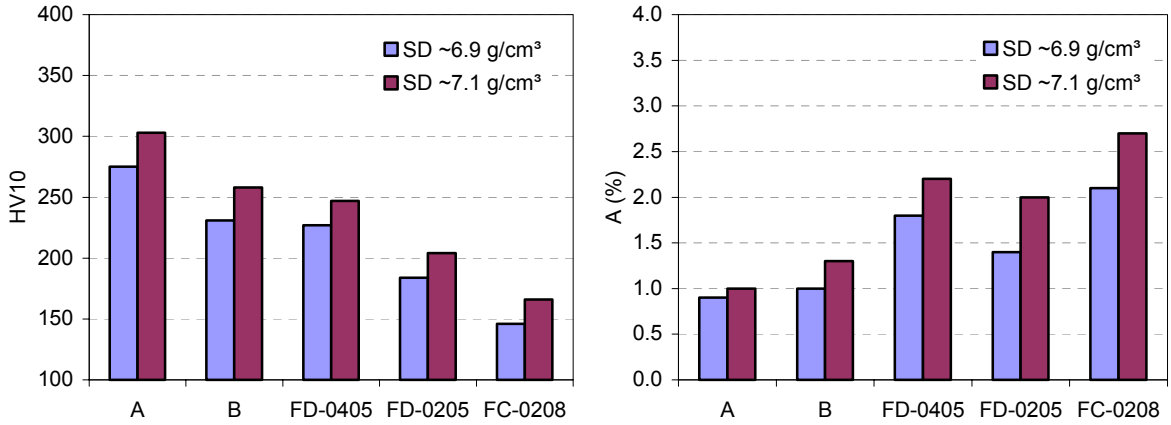


Figure 4 and 5: Hardness and elongation for sintered materials

In Figure 6 – 9, comparisons are made between mechanical properties as sintered and as sinter hardened. Material A is of identical composition in as sintered and as sinter hardened states. Material B and C are from the same base powder, Astaloy CrL, but of different mix compositions. For sinter hardening, 1% copper is added to increase hardenability in order to form martensite at the cooling rate 2 – 3°C/s.

Both material A and B (designated C in sinter hardened state) change from a mainly bainitic to martensitic structure by using sinter hardening. Tensile strength, and to an even larger extent, yield strength, are increased by sinter hardening, see figure 6 and 7. Material A, with the highest alloying content, achieved the highest tensile and yield strength in both sintered and sinter hardened states.

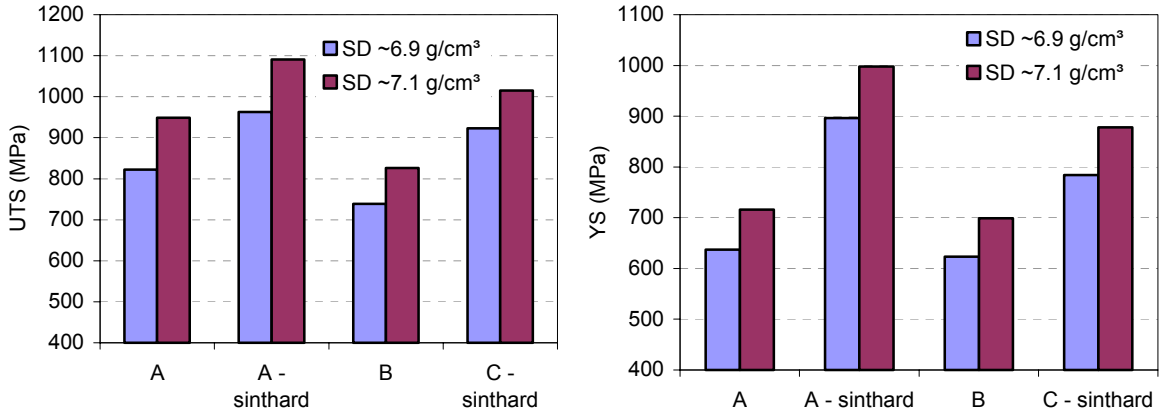


Figure 6 and 7: UTS and YS for sintered and sinter hardened materials

Hardness is also improved by sinter hardening, see figure 8. Material A is harder than material B, both in sintered and sinter hardened states. For both material A and B, elongation drops from 1% to below 0.5% by using sinter hardening. Elongation is only marginally higher for material B.

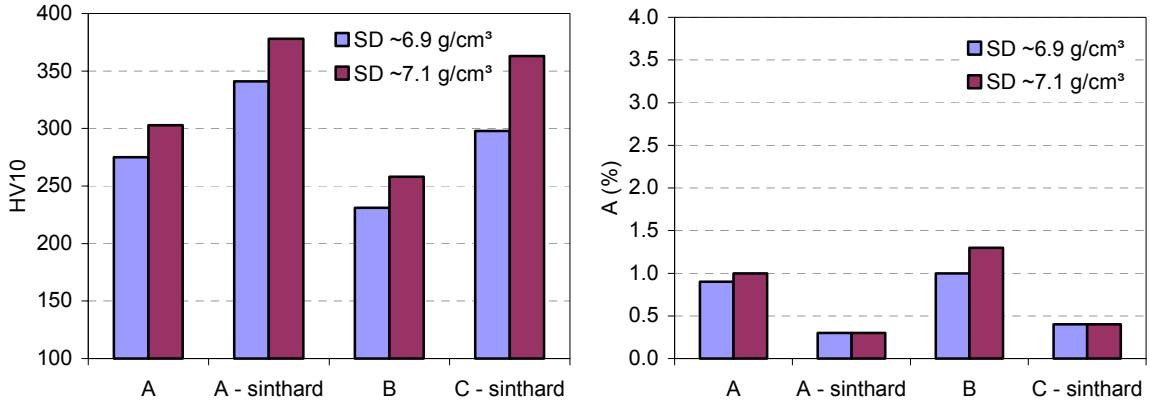


Figure 8 and 9: Hardness and elongation for sintered and sinter hardened materials

Bending fatigue strength, 90% probability of survival

Table 4 presents the fatigue strength of four materials, all sintered with a cooling rate of ~0.8°C/s. The highest fatigue strength is obtained by material A. This material has a structure of upper bainite, in which the cementite particles are finely dispersed, and 10% martensite. Material B has a structure of lower bainite. It has been found that the fatigue strength of pre-alloyed materials is controlled by which type of bainite is formed. The level and type of alloying element play an important role in the outcome.

The second highest bending fatigue strength is obtained by FD-0405. This type of diffusion-alloyed material is known to give good fatigue properties. The heterogeneous structure consists of pearlitic base powder particles reinforced by the network of the sinter necks,

composed of martensite and austenite. By reinforcing the sintering necks a substantial increase in fatigue strength is achieved compared to a pure pearlitic structure. In this comparison, FD-0405 has lower carbon content compared to FC-0208. If fatigue strength is compared at a similar carbon level, the difference between the two alloying systems would be larger. Areas or nickel-rich austenite also act as crack arrests, which is beneficial for fatigue strength.

The 90% probability fatigue life of material B is at a level comparable to the Fe-Cu-C alloyed material FC-0208, even though the static strength of material B is superior compared to FC-0208.

Table 4: Bending fatigue properties, 90% probability of survival

Material	% C sint.	S.D. [g/cm³]	$\sigma_{A,\ 90\%}$ [MPa]	Microstructure
A	0.46	7.10	261	Upper Bainite+ few areas of Martensite
B	0.74	7.08	225	Lower Bainite.
FD-0405	0,63	7.11	243	Pearlite, Martensite, Austenite.
FC-0208	0.79	7.15	222	Pearlite, some cementite.

Microstructures

Material A sintered with a cooling rate of ~0.8°C has a structure with 10% martensite, the rest is upper bainite with fine dispersed cementite particles, see figure 10. Finer dispersed cementite is achieved by material A compared to that obtained by e.g. a pre-alloyed 1.5% Mo alloy under the same processing conditions. Under sinter hardened conditions, material A has a fully martensitic structure.

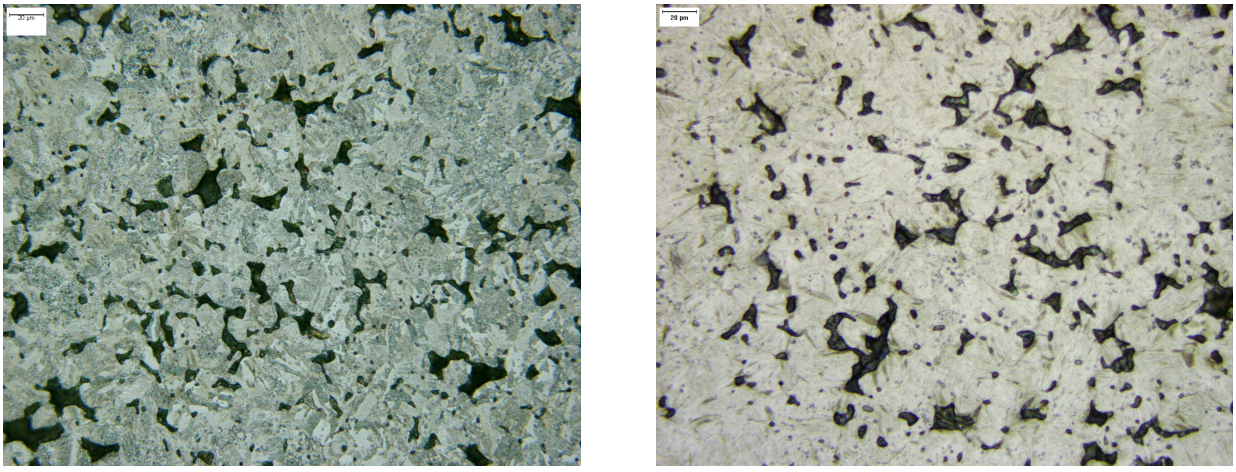


Figure 10: Microstructure of material A, as sintered (left) and as sinter hardened (right)

A feature of material B at a cooling rate of ~0.8°C/s is that the structure consisting wholly of lower bainite, see figure 10. Material C as sinter hardened has a martensitic structure with 2-3% bainite.

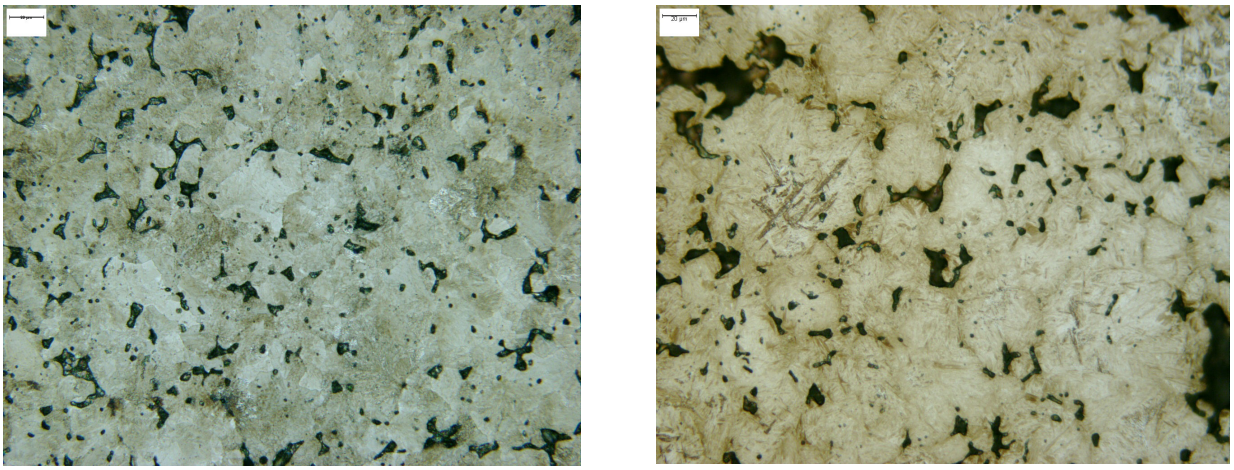


Figure 11: Microstructure of material B as sintered (left) and material C as sinter hardened (right)

FD-0405 and FD-0205 have heterogeneous structures typical for diffusion-alloyed materials, see figure 12. In these structures, pearlite is found in the centre of the original iron powder particles. A border with ferrite is found around the pearlite phase. In areas where the alloying content is higher, the structure is martensitic. Areas of nickel-rich austenite are also seen.

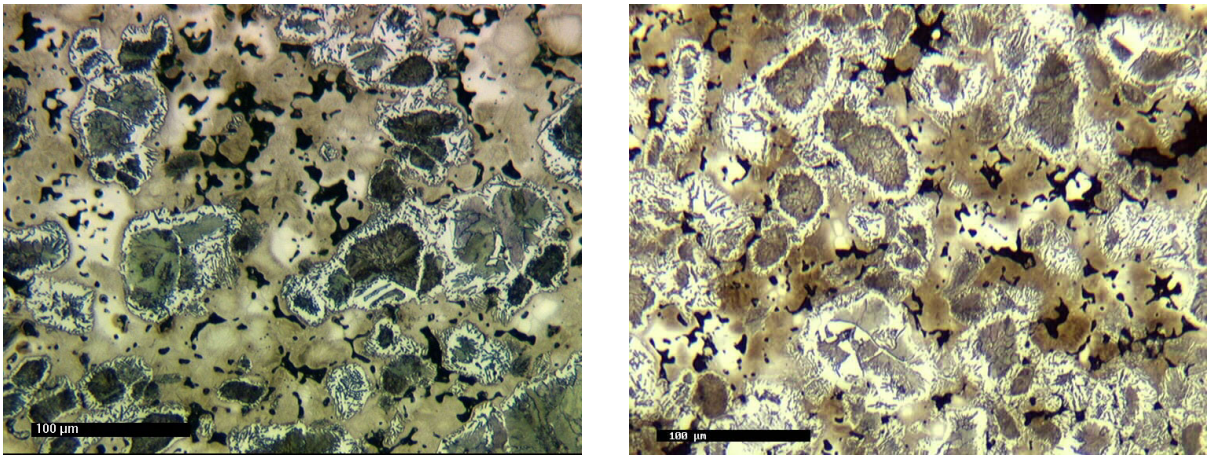


Figure 12: Microstructure of FD-0405 as sintered (left) and FD-0205 as sintered (left)

The structure of FC-0208 consists mainly of pearlite, see figure 13.

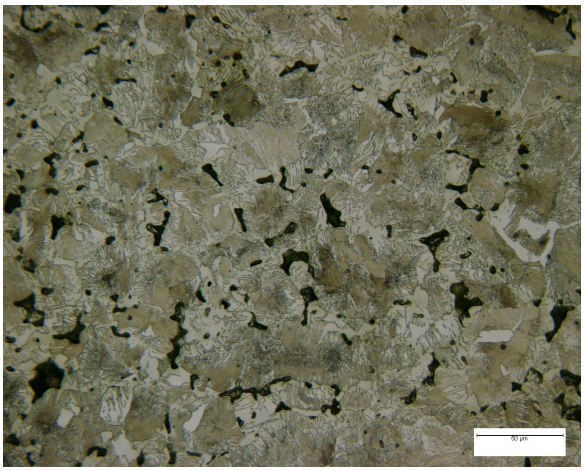


Figure 13: Microstructure of FC-0208 as sintered

Conclusions

Compared at similar density, both Cr/Mo pre-alloyed materials A and B have tensile strength exceeding that of FD-0405. The yield strength of these pre-alloyed materials is more than 50% higher than that of FD-0405. Elongation is lower for the pre-alloyed materials than for FD-0405.

Compressibility is lower for Cr/Mo pre-alloyed base powders, Astaloy CrM and CrL, compared to diffusion-alloyed base powders, Distaloy AE and Distaloy AB. This is due to solution hardening.

At the selected levels of carbon, highest fatigue strength (90% survival) is obtained by material A (0.46% C), exceeding that of FD-0405 (0.63% C). Material B (0.74% C) matches the high-performance diffusion-alloyed materials with respect to strength and hardness, when compared at the same density. Fatigue life is however lower than for FD-0405 and is at the level of Fe-Cu-C material FC-0208 (0.79% C).

Both Cr/Mo materials A and C are suitable for sinter hardening and achieve martensitic structures at a cooling rate of 2 – 3°C/s. High strength is obtain by these materials as sinter hardened. As sinter-hardened, material A has higher tensile and yield strength, whereas hardness and elongation are similar.

References

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