High Performance Sinter Hardening Materials for Synchronizing Hubs

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ABSTRACT

The development of synchronizing hubs goes towards more complicated shapes and higher performance, at the same time as there is a strong pressure on costs. Today many high performance synchronizing hubs are produced using different diffusion bonded materials like Distaloy AE and Distaloy HP. With the new demands it is a desire to move to materials and processes with better cost/performance ratio. This means to move away from high and unstable costs for pure nickel and molybdenum to pre-alloyed materials preferable based on chromium with none or smaller additions of plain nickel.

Astaloy CrA and Astaloy LH are pre-alloyed powders suitable for sinter hardening. By selecting different additions of copper or nickel as well as the carbon content the properties can be tailored for different strength requirements. The usage of CCT-diagrams can assist in the selection of the optimal composition depending on which cooling rate that can be applied.

INTRODUCTION

New synchronizing hubs are in general more complicated in their shape, with complex multi-level designs and thin wall sections. This requires complex tool concepts, effective powder filling and advanced compaction control. When it comes to the mechanical properties, these requirements also have increased. The demand is for higher hardness, yield and fatigue strength in combination with high toughness and tight tolerances. All these requirements have to be achieved in a cost effective way.

There are different ways to achieve this. When looking at the materials side more effective powder filling, including more even as well as faster filling, is possible to obtain by using different types of bonded mixes. The bonding of fine constituents will also improve the tolerance as alloying elements are getting more evenly distributed and the working environment is improved due to less dust.

When it comes to mechanical properties it is important to tailor the material composition based on the requirements and the processing conditions that are available. Sinter hardening, which is a one step process, combines good manufacturing economy with the ability to achieve unique combinations of mechanical properties. It has been found to be a very cost effective process route for high performance synchronizing hubs. You can either use a lower alloyed material in order to reach the same mechanical properties as in earlier generations of hubs or different tailored compositions for hubs with higher requirements. The need of alloying elements is strongly depending on the part size and the effective cooling rate of the parts that can be achieved in the sintering furnace. When studying this it is very helpful to utilize CCT-diagrams.

Nickel is an excellent alloying element to work with when you are targeting a combination of strength and ductility. However, during the last 10 years the prices have been volatile and shown an increasing trend for the time being, especially in the powder form. Therefore it is of great interest to look at alloying system without or with lower nickel content.

EXPERIMENTAL PROCEDURES

Material

In this investigation an iron powder prealloyed with 1,8 % Cr, Astaloy CrA has been evaluated. It has been tested plain and with addition of -100 mesh copper as well as fine electrolytic nickel powder. Fine natural graphite, uf 4, has been admixed with an amount of 0,6 % to all mixes. The lubricant Lube E has been added in the same amount. The following compositions have been tested, see table 1 below.

Table 1. Composition of test mixes

	Astaloy CrA	% Cu -100 mesh	% Ni INCO 123	% graphite uf4	% lubricant Lube E
A.	Fe-1,8 % Cr			0,6	0,6
B.	Fe-1,8 % Cr	1,0		0,6	0,6
C.	Fe-1,8 % Cr	2,0		0,6	0,6
D.	Fe-1,8 % Cr		1,0	0,6	0,6
E.	Fe-1,8 % Cr		2,0	0,6	0,6

Processing

Tensile strength test bars (ISO 2740), impact test bars (ISO 5754) and fatigue test bars (ISO 3928) have been compacted in a hydraulic press at 620 MPa aiming to reach a green density of 7,0 g/cm^3. Cylindrical specimens with a diameter of 6 mm were compacted at 600 MPa for the dilatometer trials.

Test bars were sintered in a production furnace at 1120ºC for 20 minutes in a 90/10 N_2/H_2 atmosphere. Conventional sintering with a cooling rate of approximately 1 ºC/s was compared to sinter hardening with a cooling rate above 5 ºC/s. The sinter hardened specimens were tempered at 200ºC for 60 minutes in air for stress relive.

The dilatometer samples were pre-sintered at 1120ºC for 20 minutes in a 95/5 N_2/H_2 atmosphere.

Evaluation

Dimensional change was measured from die to sintered on the tensile strength test bars. These test bars were also used for measurement of sintered density by Archimedes technique. The Vickers hardness was measured using 10 kg weight on both the upper and lower side of both ends of 2 tensile strength test bars. Fatigue strength was evaluated as plane four point bending with a frequency of 25-30 Hz and a load ratio R-1. Testing was done using the staircase method according to MPIF Standard 56. A run out limit of $2*10^6$ cycles was set. The endurance limit has been determined at 50 % survival.

CCT-diagrams were evaluated using a Theta dilatometer. Pre-sintered cylindrical samples were heated with a heating rate of 5 ºC/s. They were then kept at 1120ºC for 10 minutes before cooled with different cooling rates in the range of 0,25-10ºC/s.

RESULTS AND DISCUSSION

Mechanical properties

The specimens based on plain Astaloy CrA with 0,6% graphite reached a sintered density of 7,02 g/cm^3, see table 2. When adding copper the material show some swelling why the density decreases a couple of hundreds. The nickel addition on the contrary causes some shrinkage and thereby slightly higher sintered density then the plain Astaloy CrA.

Table 2. Sintered properties

	dT/dt °C/s	C %	DC %	SD g/cm³	HV10	YS MPa	TS MPa	A %	IE J	FS50 % MPa
Astaloy CrA	1	0,49	0,01	7,02	154	432	605	2,8	20	NA
Astaloy CrA+1%Cu	1	0,50	0,19	7,00	187	559	703	1,3	14	NA
Astaloy CrA+2%Cu	1	0,52	0,37	6,95	211	558	757	0,9	15	NA
Astaloy CrA+1%Ni	1	0,52	-0,08	7,06	201	565	746	1,7	21	NA
Astaloy CrA+2%Ni	1	0,52	-0,14	7,07	241	633	859	1,1	18	NA
Astaloy CrA	>5	0,47	0,05	7,02	301	892	985	0,3	15	235
Astaloy CrA+1%Cu	>5	0,47	0,20	7,00	320	966	1056	0,4	12	265
Astaloy CrA+2%Cu	>5	0,48	0,44	6,94	340	986	1028	0,3	12	NA
Astaloy CrA+1%Ni	>5	0,47	-0,09	7,05	366	1028	1083	0,3	15	315
Astaloy CrA+2%Ni	>5	0,49	-0,14	7,07	411	991	1066	0,3	16	330

The sintered yield strength increases from 432 MPa for the plain Astaloy CrA to 559 MPa with copper added and further up to 633 MPa with 2 % nickel added, see figure 1. When the materials are sinter hardened the yield strength is increased considerably. With an addition of 1 % nickel the yield strength is at 1028 MPa whereas the other copper and nickel containing materials are slightly below 1000 MPa.

The tensile strength follows the same pattern as the yields strength. For conventional sintering the tensile strength is 150-200 MPa above the yield strength whereas the increase is reduced to 50-100 MPa for the sinter hardened materials, see table 2.

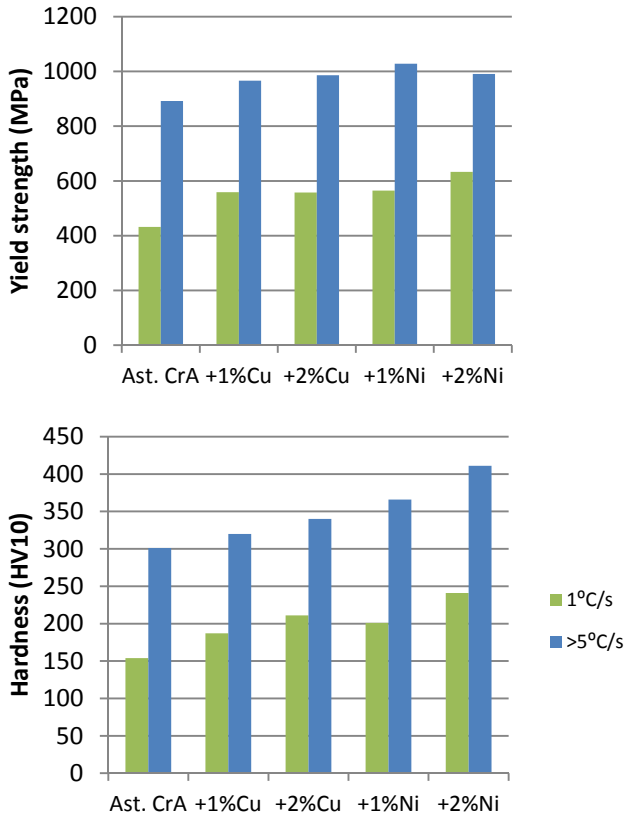


Figure 1. Yield strength and Vickers hardness of plain Astaloy CrA and with addition of copper or nickel for two different cooling rates.

The Astaloy CrA material has a Vickers hardness (HV10) of 154 after conventional sintering, see figure 1. The nickel addition leads to a larger hardness increase compared to the copper addition. At an addition of 2 % nickel the hardness is increased up to 241. By using sinter hardening the hardness is increased considerably for all compositions. The hardness values are in the range of 301-411.

Elongation starts at 2,8 % for plain Astaloy CrA in the sintered condition, see figure 2. With the copper or nickel addition the strength is increased whereas the elongation decreases. With copper or nickel added the elongation values are in the range of 1,7 to 0,9 %. The drop is larger for materials with copper added. This can be explained by the lower density. The copper swelling causes a lower density as the compacting pressure and green density were the same for the tested materials. The sinter hardened materials show low elongations of 0,4 % or below. This is due to the fact that all materials are very high in hardness.

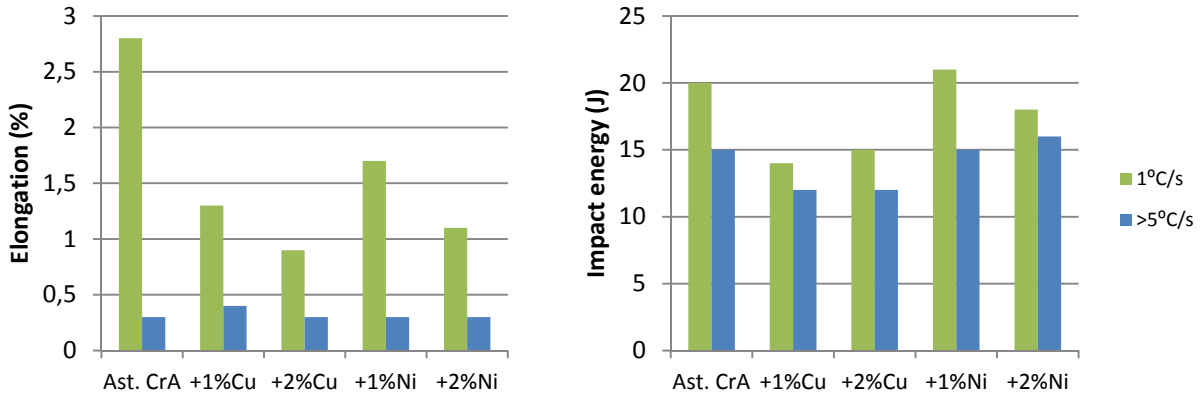


Figure 2. Elongation and impact energy of plain Astaloy CrA and with addition of copper or nickel for two different cooling rates.

Impact energy is another way of measuring the ductility of the material. The impact energy is strongly depending on the density. Due to this we can see the higher values for the plain Astaloy CrA and for material with nickel added, see figure 2. Here we have impact values of 18-21 J for conventionally sintered materials. After sinter hardening, all materials still show rather high impact energy. They are at 12 J for the copper containing materials whereas the plain Astaloy CrA and Astaloy CrA with nickel addition are in the range of 15-16 J. That is quite high for sinter hardened materials at densities of 7,0-7,1 g/cm^3.

The plain bending fatigue strength was evaluated for sinter hardened materials. The fatigue properties are very high, as all materials have taken hardening during sintering and show HV10 >300. The fatigue strength is increased with increased alloying content as hardness is increased thereby. The increase is somewhat lower for the copper addition. This can partly be explained by the lower density caused by the copper swelling. The plain Astaloy CrA has a fatigue strength of 235 MPa in the sinter hardened condition, see figure 3. With an addition of 1 % copper this is increased up to 265 MPa. The nickel containing materials show shrinkage instead during sintering, why the increase in fatigue strength is even larger. The addition of 1 % nickel increases the fatigue strength by 60 MPa up to 315 MPa. An addition of 2 % nickel increases the fatigue strength another 15 MPa up to 330 MPa.

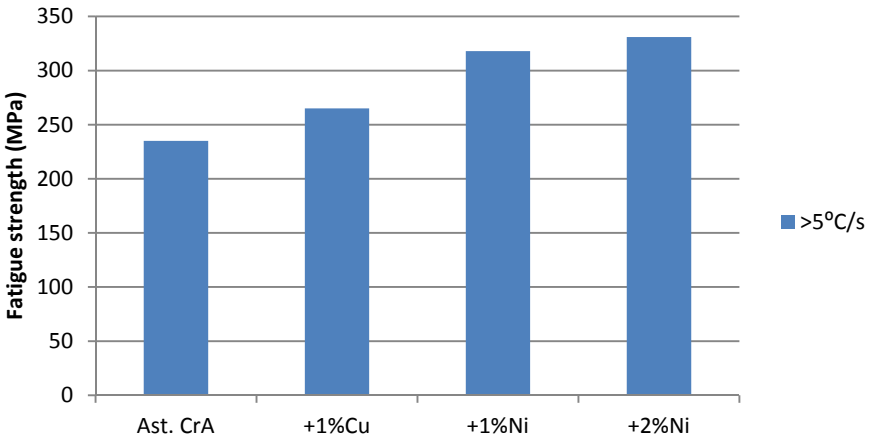


Figure 3. Fatigue strength of plain Astaloy CrA and with addition of copper or nickel after sinter hardening.

Metallography

The metallographic investigation shows that the plain Astaloy CrA with 0,5 % C has a very dense perlitic microstructure, see figure 4a. This material has a tensile strength of 605 MPa. When 2 % Ni is added the perlite becomes even more dens and there is also a small amount of very dens bainite, see figure 4b. The amount of martensite is 15 % and a few nickel-rich austenite areas are seen. The shrinkage of the material and the change in microstructure to partly martensite and finer perlite explains why the tensile strength is increased to 859 MPa.

When applying sinter hardening all materials get mainly martensitic with some smaller amounts of fine perlite and bainite, see figure 4c-f. The phase amounts are rather similar for the different materials.

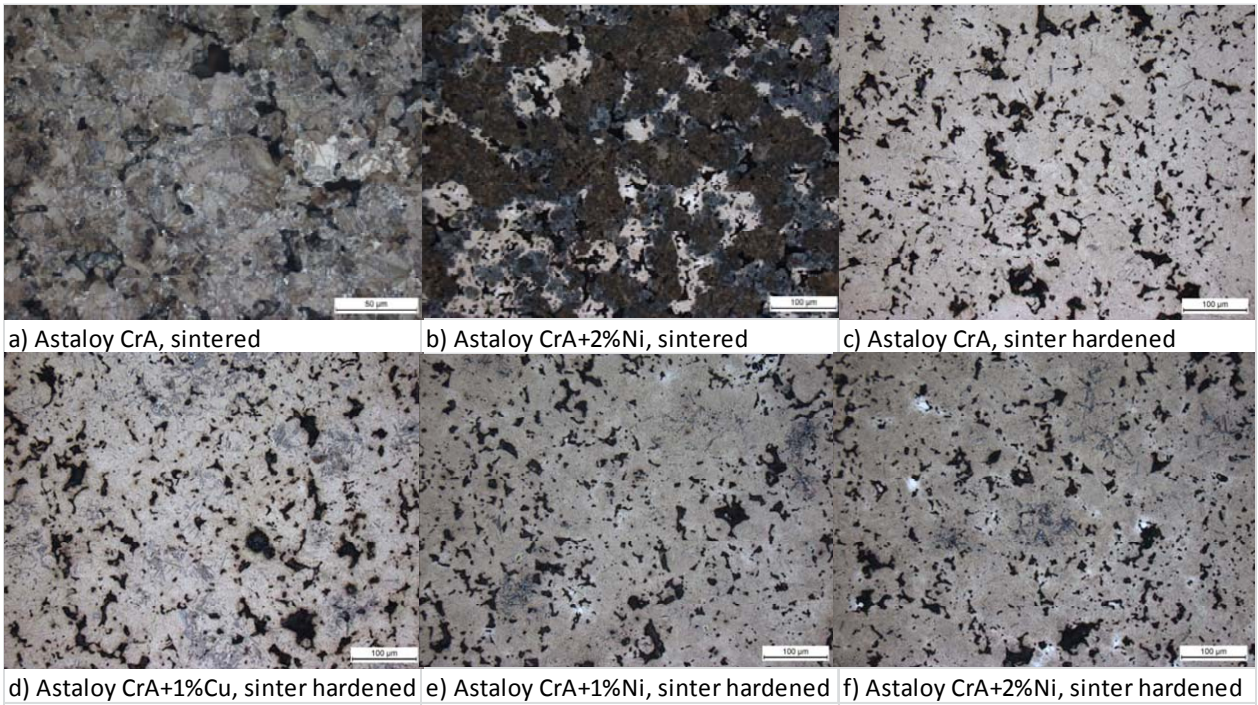


Figure 4. Etched microstructures for some selected sintered and sinter hardened materials. Structure a) is in slightly larger magnification.

CCT-diagrams

The CCT-diagrams for Astaloy CrA and Astaloy CrA + 2 % Cu has been evaluated at a carbon content of 0,5 %, see figure 5. Here it can be seen that the perlite is the dominating phase at a cooling rate of 0,25ºC/s. Bainite and martensite starts to form already from 0,5ºC/s, increasing hardness and strength. The copper addition moves the perlite transformation curve towards longer times and slower cooling rates and moves parts of the bainite line towards higher temperature. For the copper containing material the perlite phase disappears between 1,5 and 2,5ºC/s and results in increasing amounts of bainite and martensite. The bainitic phase is still present at a cooling rate of 5ºC/s. The microstructures have to be investigated in order to determine the phase amounts.

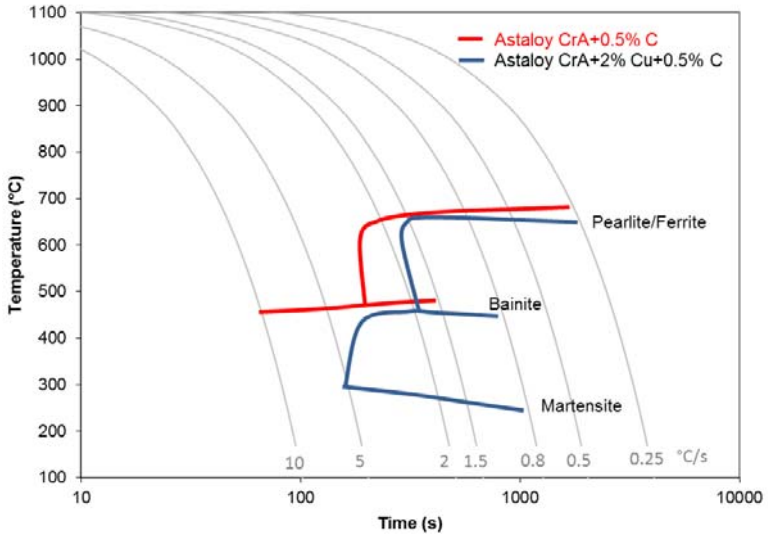


Figure 5. CCT-diagram for Astaloy CrA and Astaloy CrA + 2 % Cu at a carbon content of 0,5 %.

The metallographic investigation of the dilatometer samples show that the Astaloy CrA material with 2 % Cu is perlitic with only 1 % of martensite at the lowest cooling rate of 0,25ºC/s. By increasing the cooling rate up to 0,5ºC/s the amount of martensite is increased up to 16 % and 4 % of fine bainite is formed. An increase in cooling rate up to 5ºC/s makes the microstructure martensitic with only 4 % of fine lower bainite.

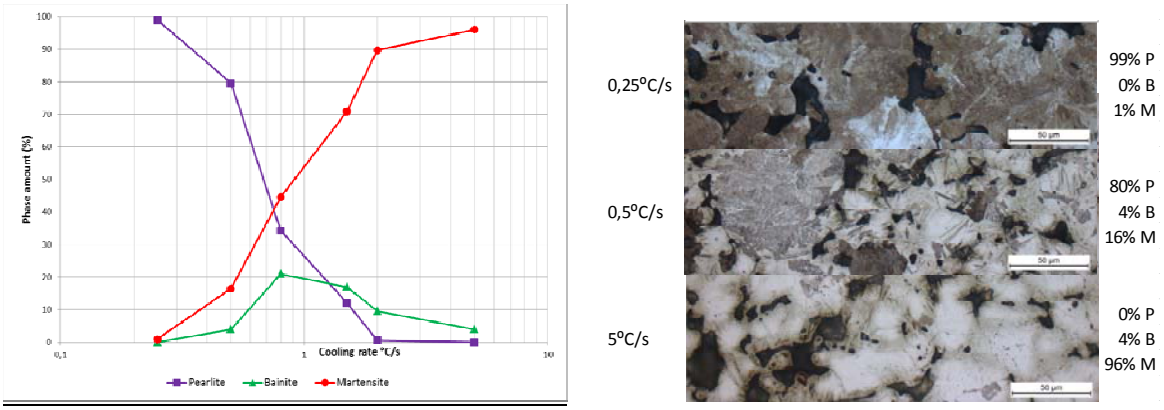


Figure 6. Phase amounts of Astaloy CrA + 2 % Cu + 0,5 % C at different cooling rates in the range of 0,25 to 5ºC/s, with corresponding microstructures.

CONCLUSIONS

- Sinter hardening of a pre-alloyed iron powder with 1,8 % Cr results in a good cost-performance ratio
- A yield strength of 890 MPa and impact energy of 15 J is achieved at a carbon content of 0,5 %.
- The mechanical properties are improved further by adding 1-2 % copper, resulting in yield strength values of 966-986 MPa
- An addition of 1-2 % Ni gives further increase of the yield strength to 991-1028 MPa and plain bending fatigue strength of 315-330 MPa
- Studying CCT-diagrams and microstructures are effective tools when tailoring the composition for a specific set up of sintering conditions