

# Microstructure and properties of new developed Fe-Cr-C-B powders for wear-protection purposes

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## Abstract

In wear protection of machinery parts from cement-, mining-, metallurgy and agriculture industry it is state-of-art to apply durable and cheap coatings with alloys from the system Fe-Cr-C-B. Since these parts are often exposed to extreme abrasive wear there is a need for thick coatings which are usually produced with cored wires. These wires can also be designed for the use in arc-spraying or flame spraying process to produce coatings within the range from 0.2 mm to some mm. However the characteristic of both processes is not suitable for all technical requirements which often need more dense coatings with higher bond strength. In this article the research on new, completely alloyed Fe-Cr-C-B powders which can be applied with HVOF spraying techniques is presented. To achieve high wear protection the content of chromium lies in the range of 30weight% and carbon content is about 5weight% which causes a unique powder structure and coatings with a homogeneous high carbide content. The powders and coatings are examined by metallographic analysis including SEM microscopy. The tested wear behavior is presented and underlines the use of this material for several wear protection purposes. Moreover it is discussed how far these completely alloyed powders can partially substitute conventional carbide coatings.

## Introduction

Machine parts and units are faced to different stresses. Wear - which usually starts on the surfaces – gobbles up enormous amounts of money in every national economy. Therefore many processes and strategies for protecting surfaces or repairing worn out parts have been developed. Thermal spraying processes play an increasing important role and still show a high developing potential (Ref 1).

This is due to a wide range of optimized processes which are applicable to tasks from the electronic industry requiring thin functional coatings up to thick coatings for the ventilator industry. Besides the processes the spraying materials are of a big interest in research and development. Regarding anti-wear coatings one can see various tendencies in material development for thermal spraying. Against the background of achieving longer life time of machine parts and units the optimization of material compositions for different applications is a big point. An often quoted example is the replacement of hard chrome (Ref 2). However for remaining competitive against other technologies and moreover for

conquering new markets there is also a need to develop new spraying materials which are a) better in their properties or b) lower in their costs with almost same properties during application. Latter is often described in literature with the attempt to substitute expensive Ni,- Co- or WC coatings with iron base materials (Ref 3, 4) .

The intension of this paper is to show the properties of new developed Fe-Cr-C-B powders in comparison with two conventional carbide coatings. The new developed iron-base powders are produced via melt atomization and therefore completely alloyed.

## Experimental

### Powder feedstock

Three different kinds of powders were produced via melt atomization. The chemical composition (Table 1) is similar to established cored-wires of the type Corthal® from Corodur Verschleiss-Schutz GmbH which serve as hardfacings against abrasive wear. These wires can be processed by open-arc welding. The manufactured powders were screened to a grain size of 20-45µm. As comparison two commercial carbide powders were utilized. A tungsten carbide based powder from type WC/Co 88/12 was supplied from Sulzer Metco with the product name Woka 3102 (15-45µm). The other utilized carbide powder 25NiCr-75CrC is commercially available under the name Woka 7202 (15-45µm).

Table 1 Chemical composition of tested powders in weight percent

	C	Si	Mn	Cr	B	Nb
Powder 1	4.7	2.3	0.2	28.9	-	-
Powder 2	5.2	2.0	0.3	30.0	0.5	
Powder 3	4.2	2.0	0.2	26	-	2.2

### HVOF Thermal spraying process

The coatings were produced using the Sulzer Metco Diamond Jet spraying gun DJCE with propane as fuel. The powders were volumetric-controlled fed with the commercial powder feeder TWIN 120-E. Every powder was sprayed with the same parameters (Table 2). Approximately 0.3 mm thick coatings were produced without the use of a bond coating.

Table 2 Spraying parameters using the Sulzer Metco DJCE spraying gun

O2	C3H8	Air	Overrun	distance
267 slpm	57 slpm	329 slpm	30 m/min	275 mm

**Metallography**

The powders and coatings were analyzed by means of conventional light microscopy. For higher resolutions (>500 times) SEM microscopy with attached EDX was used. For reliable analyses of appearing phases within the powders and coatings X-ray fluorescence analysis was carried out on powders and coatings of powder 2. The visible microstructure on the presented pictures was developed using the etching agent “VA-Beize”. As embedding agent for the powders a combination of copper powder and hardener was used. Therefore red shining small particles can be seen in the microsections of the powders which represent the copper particles (“X” in Figs. 1 and 4).

**Wear Tests**

The wear tests were carried out using a Harworth – ZIS – testing device. The coated specimens with the dimension 20 x 20 mm<sup>2</sup> are pressed against a rotating wheel. This equipment makes it possible to test under 2-body- and 3-body-abrasiv wear conditions. While the 3-body-abrasiv wear test is done with a Hardox 500 steel-wheel a rubber wheel is used to test under 2-body-abrasive wear conditions. Both tests were using dry sand as abrasive with an available grain size of 0.1 – 0.3 mm. In order to measure only the influence of the coatings the force pressing the specimens on the rotating wheel was set on 30 N. The wear is determined by the weight loss and presented as wear intensity (by relating the weight loss to the wear distance).

**Results**

**Powder Feedstock**

The microsection in Fig. 1 shows the powder 2. The morphology of the powders ranges from tear drop like to spherical. One can see that the powder particles show a uniform microstructure with more or less white phases surrounded by a grayish-black matrix. The appearance of the white phases is similar to that of iron-chromium-carbides known from hardfacings. Depending on the section plane these carbides can be seen as needles or as hexagons.

Table 3 Hardness of different carbides (Ref 5, 6, 7)

\*HV0.05

	VC	WC	TiC	Cr <sub>7</sub> C <sub>3</sub>	(Fe-Cr) <sub>7</sub> C <sub>3</sub>	Mo <sub>2</sub> C	NbC
hardness [HV]	2940	2350	3200	2200	1300 – 1600*	1660	1800

It has been the intention of this work to produce powder particles build up of carbides with chromium as main alloying element. These carbides are not the hardest known carbides however one of the most effective. The achieved hardness (Table 3) is sufficient that many minerals can't scratch them and the formulation of chromium-carbides is relatively cheap requiring chromium and carbon as alloying elements. Moreover iron can be used as base material. For the wear behavior pure chromium carbides are preferred since the formation of iron-chromium-carbides reduces the carbide hardness.

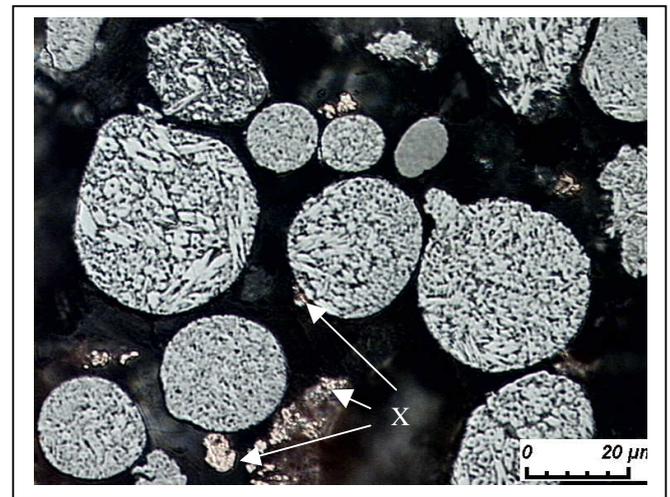


Figure 1: microsection of powder 2, 500x

The XRF-analysis in Fig. 2 proved that there are pure chromium-carbides in the microstructure of powder 2 (“A”, “C”, “D” in Fig. 2). It was actually expected to find iron-

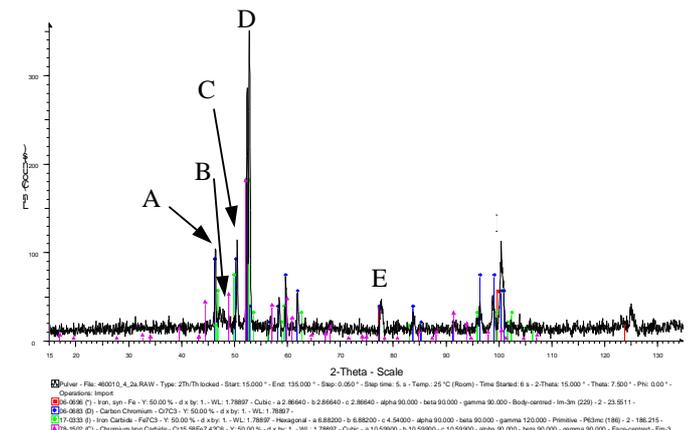


Figure 2: XRF analysis of powder2

chromium-carbides instead of pure chromium carbides. Therefore different mixed carbides were checked whether they suit to the analysis. The pink triangles represent the most probable ones. However there is no real peak nearby.

Therefore it is very likely that no important amounts of iron-chromium-carbides exist besides pure chromium carbides. A main peak ("A") between 52° and 53° belongs to body centered iron which is slightly adjusted ("E","F") with higher 2-theta-angles. Moreover the double peak at 46° and 47° ("B") suggests that the microstructure contains Fe<sub>7</sub>C<sub>3</sub>. Unfortunately it wasn't possible to detect to which phase the low amounts of boron are linked with.

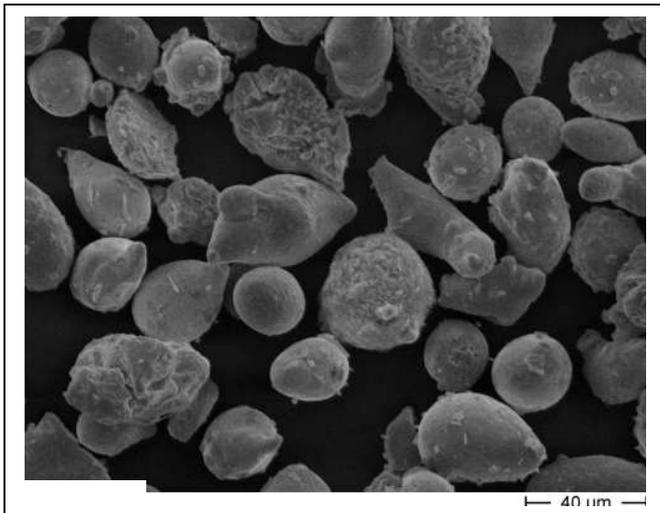


Figure 3: SEM picture of powder3, 500 x

Figure 3 and Figure 4 show the morphology and microstructure of powder 3. The addition of niobium seemed to have an influence on the viscosity of the melt since the droplets are not looking as spherical as seen for the powders 1 and 2. The comparison of Fig. 1 and Fig. 4 indicates a different microstructure for powder 3. Some particles don't seem to react during etching and remain in a

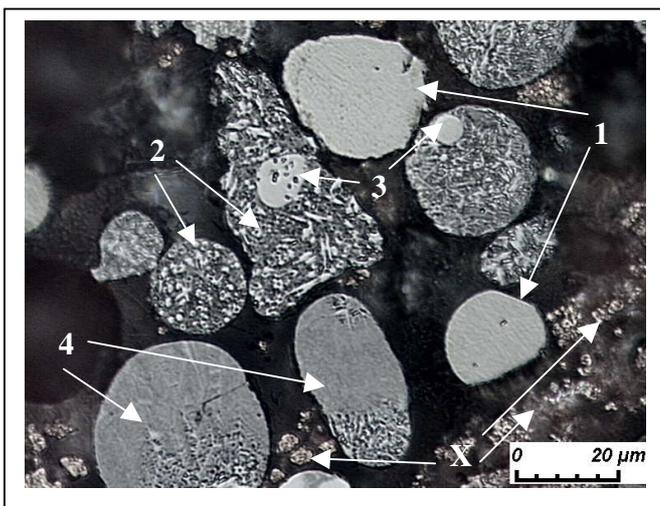


Figure 4: microstructure of powder 3, 500x

grayish color without any structure ("1" in Fig. 4). Other particles show the typical (iron-) chromium-carbides but not as densely packed and not as big grown ("2" in Fig. 4) within each particle as it can be seen in Fig. 1 for powder 2. Within two particles two grayish particles seem to be incorporated ("3" in Fig. 4). On the bottom of the Fig. 4 are two particles with merging structures ("4" in Fig. 4).

The two different microstructures can be explained by the addition of niobium which has a higher affinity to carbon than chromium. Due to this property MC (M: mainly Nb) dissolves some amounts of carbon first with the result that there is less carbon available for chromium. Therefore the iron-chromium-carbides are less densely packed and when the amount of available free carbon drops – even locally – under the hypereutectic amount no primary carbides will be formed. Against the background of this effect the chemical composition of the powder 3 should be designed again. Obviously the carbon content is not sufficient. The assumption that the incorporated grayish particles are niobium carbide particles will be later analyzed on the coatings.

#### Coatings

The powders were sprayed with the standard parameters without any problems during feeding. Although there was no bonding material sprayed before coating with the hard alloys the coatings show a good bonding to the substrate. The difference between the powders 1 and 2 is small and so the spraying results are almost similar. Figure 5 shows the coating produced with powder 1. The porosity could be kept low (< 5 %) even with the not optimized standard spraying parameters.

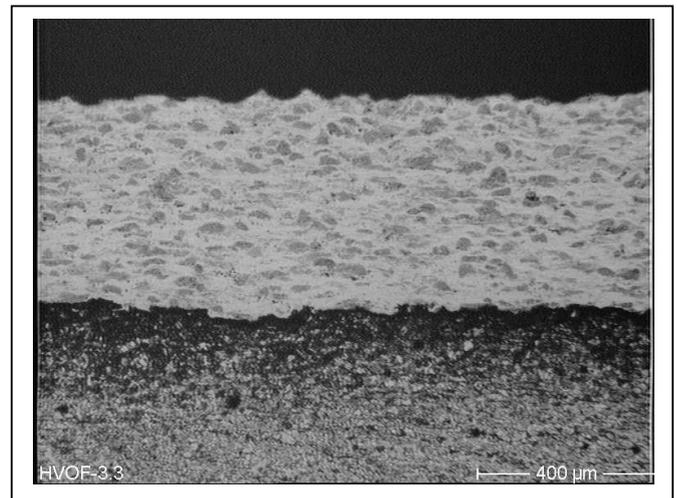


Figure 5: LM picture of sprayed coating made of powder 1, 63x

The coating is build up of molten and not completely molten particles. The completely molten particles are not so easy to etch. That difference could not be observed for the powder. However, with higher magnification (Fig. 6) it is visible that

even these brighter areas have uniformly distributed iron-chromium-carbides in their microstructures.

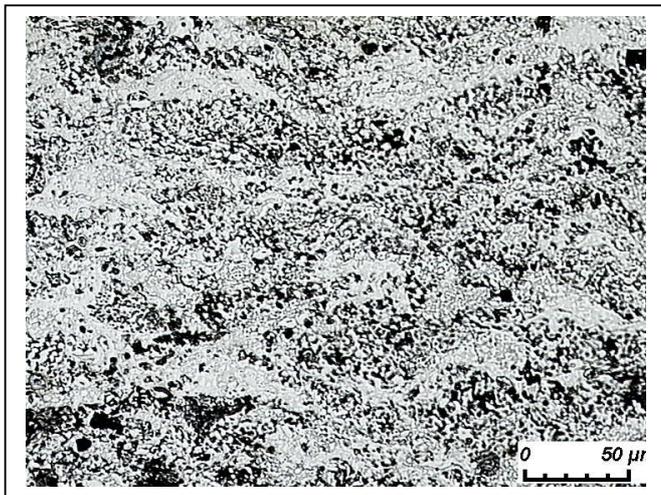


Figure 6: microsection of coatings of powder 2, 500x

This is underlined by the XRF-analyses presented in Fig. 7 since no new phases appear. It still contains the main peak (“D” in Fig. 7) for body centered iron and a second phase which is identified as pure chromium carbide (blue lines or “A”, “C”, “D” in Fig. 7). In contrast to the powder (Fig. 2) the phases  $Fe_7C_3$  and the iron-chromium-carbide couldn't be related to the XRF-analysis of the sprayed coating. Since both phases were not definitely a component in the powder it is as well not so definite to explain the existing difference between powder and coating. Regarding the Fig. 7 one can see that there is no visible peak like “B” in Fig. 2 which could be related to any different phase. However the base area (“G” in Fig. 7) around the main peak is much higher curved than the analysis of the powder. This effect can be explained either with several phases which are contained in low amounts or with phase(s) whose size lies under the resolution of the XRF analysis.

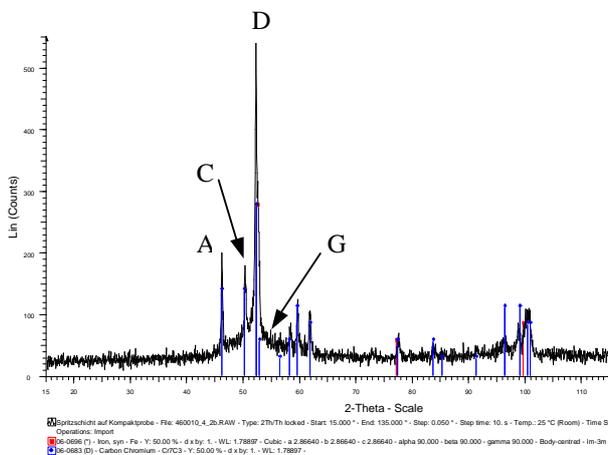


Figure 7: XRF analysis of coating made of powder 2

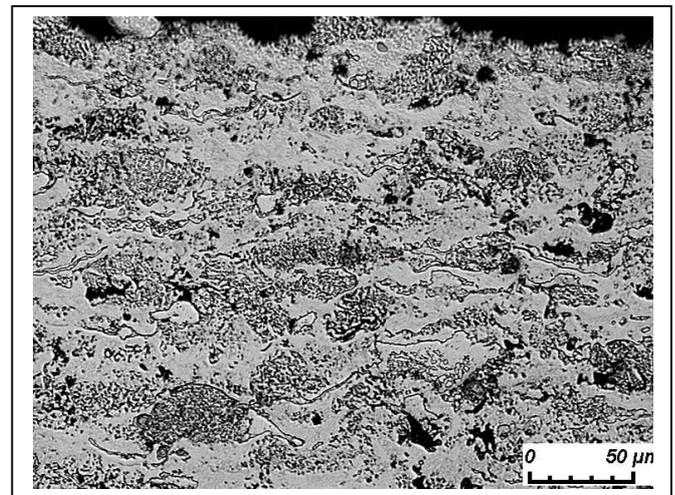


Figure 8 : XRF analysis of coating made of powder 3

The coatings made from powder 3 show a higher porosity and an inferior bonding quality between the particles (Figure 8) compared with the coatings from powder 1 and 2. In Fig. 9 one can also see that the incorporated particles of which it was assumed that they are niobium carbides are still present in the microstructure of the sprayed coating. The quantitative analysis (Table 4) proved that these phases (area 1) are rich in niobium and carbon in the typical composition of carbides from the structure MC. The other areas (2-4) are a mixture of elements containing high amounts of iron with different amounts of chromium and carbon. In the phase 4 small structures remind on the (iron-) chromium-carbides. The EDX analysis in this area results in higher amounts of chromium and carbon as seen for the areas 2 and 3.

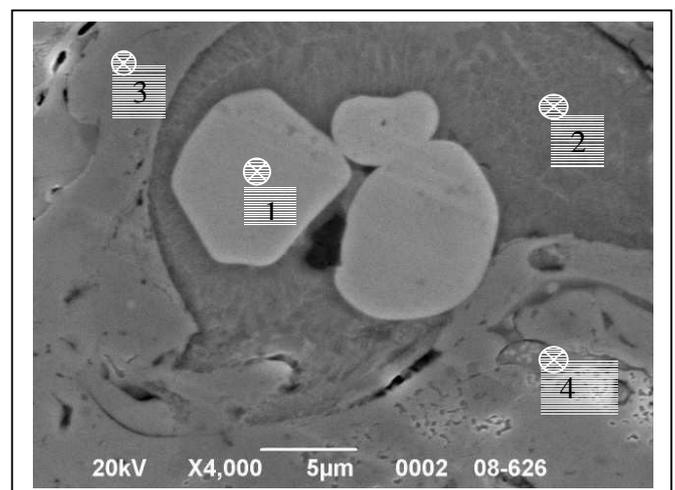


Figure 9: SEM detail of coating made of powder 3, 4000x

Figure 9 also shows that there is a disbonding between the not completely molten particles and following splats. This can result in cracking under load or easier loose of particles under abrasive attack. In the center of the 3 niobium carbides a

whole is visible. This could be a disadvantage under load, too. It seems as if the whole results from the deformation during impact of the particle.

Table 4 EDX analysis of selected areas from the Fig. 9 in the coating produced with the powder 3

	1	2	3	4
Weight % Fe	1	60	70	51.7
Weight % Nb	77.6	5.9	2,5	2.4
Weight % Cr	0.4	25	19.3	34.4
Weight % Si	-	1.5	2.0	0.9
Weight % C	21	7.6	6.2	10.6

### Microhardness

From Fig. 10 one can see that from the three new developed powders the powder 2 achieves the highest values. With an average value of 957 HV0.1 they are very close to measurements for the NiCr-CrC powder with an average value of 1002 HV0.1. The highest microhardness was observed for the coatings made of WC/Co powder. This can be explained with the higher hardness of the contained tungsten carbides compared to the (iron)-chromium-carbides as it can be seen from Table 3. However, one should consider that the size of the carbide particles WC and CrC is bigger than the primary chromium carbides are but still smaller than the microhardness indentation (HV 0.1). Thus the given microhardness values represent a mixture of values for the hard phase and the matrix.

While the microhardness of powder 1 is about 783 HV0.1 and about 845 HV0.1 for powder 3 the average value for powder 2 is about 100-170 HV0.1 higher. The chemical composition seen in Table 1 can give an explanation. The powder 2 has the highest carbon content and an amount of 0.5 weight percent boron. Both elements form hard phases what can support the hardness or rather increase the amount of hard phases.

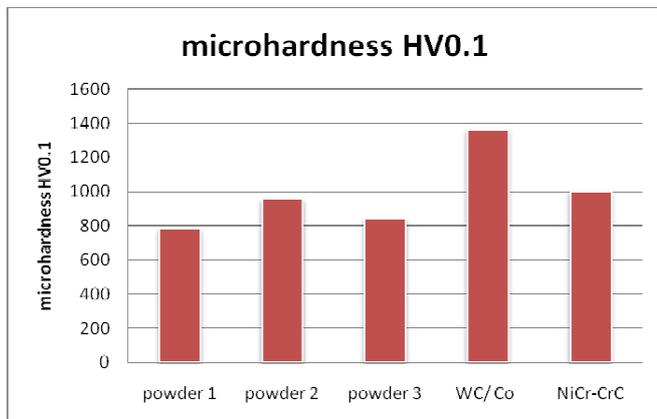


Figure 10: microhardness of the sprayed coatings in HV0.1

### Wear tests

In the 2-body wear test (Fig. 11) the coatings produced with the new developed powders show a better wear intensity compared to the two conventional carbide powders. The best results were achieved with the powder 2 while the powder 1 is only slightly inferior. In this testing method the carbide coatings produced with the powder from the type WC/ Co shows the worst results with 56% higher weight loss compared to powder 2. From the group of the new developed powders leads the powder 3 to the highest wear intensity which is about 35 % higher than for powder 2.

The results for the 3-body wear test look different. The wear intensity for the coatings sprayed with the powders 1, 2 and NiCr-CrC have almost the same values around 500 mg/km. In this testing method the WC/ Co coatings show the best results. The wear intensity of 367 mg/km is 36 % better compared to the second best coating produced with the new developed powder 2. In Fig. 12 one can also see that coatings produced with powder 3 result in coatings with the worst wear intensity. The value of 589 mg/km is about 18 % higher compared to powder 2.

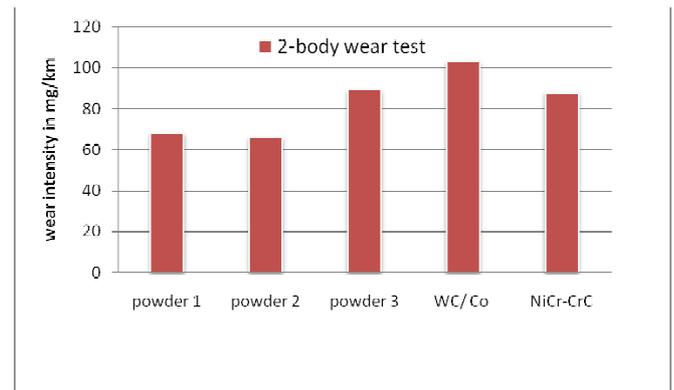


Figure 11: results from the 2-body wear test

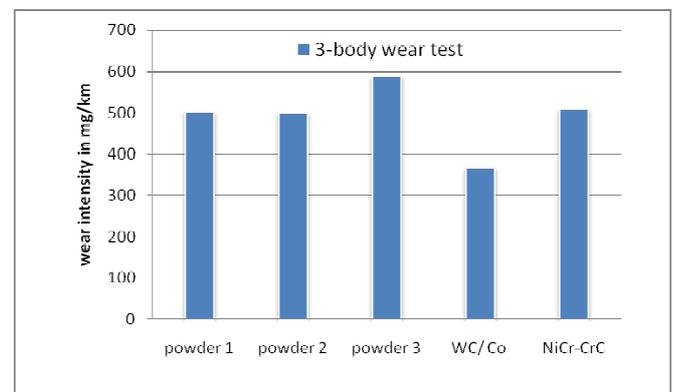


Figure 12: results from the 3-body wear test

## Summary

The aim of the work was to produce iron-base powders with embedded primary hard phases. In the first stage simple alloyed powders were designed in order to test very price attractive powders for wear protection purposes. Therefore two melt atomized powders were chosen from the system Fe-Cr-C with one powder also having boron as alloying element. Another powder was atomized which had niobium as additional alloying element in order to form fine distributed niobium carbides.

Via XRF analysis chromium carbide  $\text{Cr}_7\text{C}_3$  was identified as main primary hard phase. The metallographic examinations showed that these phases are very fine distributed in the powders and coatings.

The actual idea to increase the wear resistance with the addition of niobium was not successful yet. However the results of the alloys from the system Fe-Cr-C-B (powder 2) showed excellent results in the wear tests. Tested against a rubber wheel and dry sand as abrasive (2-body wear test) the coatings produced with the powder 2 gave the best wear results – even compared to the conventional carbide coatings WC/Co and NiCr-CrC.

Switching from a 2-body to 3-body wear test by replacing the rubber wheel against a steel wheel (Hardox 500) the wear of the tested coatings changes, too. Under that condition the WC/Co coatings give the best results followed by the coatings from the system Fe-Cr-C-B (powder 2).

It is clear that for good wear protection the analysis of the tribological system is necessary. For several industrial applications a coating consisting of hard particles embedded in a soft matrix is not the best solution. The carried out wear tests

confirm this comment. Since the hard materials can be simply washed out of the matrix it is sometimes better to choose a material with a microstructure consisting of fine distributed hard phases. Therefore the new developed completely alloyed powders from the system Fe-Cr-C-B with primary hard phases can be used to close a gap for the wear protection which consists between conventional carbide powders and low alloyed steel powders.

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