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ENGINEERING STRUCTURE AND PROPERTIES OF MATERIALS USED AS A MATRIX IN DIAMOND IMPREGNATED TOOLS

KSZTAŁTOWANIE STRUKTURY I WŁASNOŚCI MATERIAŁÓW STOSOWANYCH JAKO OSNOWA W NARZĘDZIACH METALICZNO-DIAMENTOWYCH

The paper presents mechanical properties of materials used as matrices in diamond impregnated tools. Several powder metallurgy materials were manufactured by the hot press process from various combinations of cobalt (*Co SMS, Co Extrafine, Co 400mesh*), carbonyl iron (*Fe CN*) and tungsten *(WP30)* powders. After consolidation the specimens were tested for density, hardness and tensile properties. The fracture surfaces and materials' microstructure were observed using the Jeol JSM- 5400 scanning electron microscope and the Leica DM4000 light microscope. The main objective of the work was to determine the effects of the mean particle size of cobalt as well as additions of iron and tungsten on properties of the as-consolidated material.

Keywords: PM diamond tools, cobalt, hot pressing, mechanical properties

W pracy przedstawiono wyniki badań własności mechanicznych materiałów stosowanych na osnowy narzędzi metaliczno-diamentowych. Badano spieki wykonane metodą prasowania na gorąco z proszków: kobaltu (*Co SMS, Co Extrafine, Co 400mesh*), żelaza karbonylkowego (*Fe CN*) i wolframu *(WP30).* Badania obejmowały: pomiar gęstości, twardości i statyczną próbę rozciągania. Dokonano również obserwacji mikrostruktury przy użyciu świetlnego mikroskopu Leica DM4000 i przełomów przy zastosowaniu elektronowego mikroskopu skanningowego Jeol JSM-5400. Badania prowadzono w celu określenia wpływu wielkości cząstek proszku kobaltu oraz dodatku wolframu i żelazana własności otrzymanych spieków.

1. Introduction

The advances in the production of sintered diamond impregnated segments designated for cutting natural stone, glass and other construction materials stem from the utilization of high quality synthetic diamonds and metallic-matrix materials as well as high-tech methods for the design and production of such tools.

Cobalt and cobalt alloys have been commonly used in industry to produce matrices for diamond impregnated tools. Cobalt powders are characterized by very good compactibility when hot pressed [1,2]. As a result, the final products possess high abrasive resistance and very good retentive properties with regard to diamond crystals [3-10]. One of the few drawbacks of cobalt is high and unstable price; that is why producers of diamond-impregnated tools are looking for a cheaper alternative to replace cobalt powders.

In this study, cobalt was partially replaced with iron. Moreover, some sinters were produced by adding tungsten to improve the retentive properties of the matrix [11].

2. Methodology and results

The samples to be analyzed were produced from elemental cobalt, iron and tungsten powders. The basic properties and shape of the powder particles used in the experiment are presented in Table 1 and Fig. 1.

The input materials were combined to produce four different mixtures. The mixing was performed for 1 hour using a Turbula T2C heavy-duty shaker-mixer. The elemental cobalt powders as well as the mixtures were hot pressed in a graphite die, which enables

TABLE 1
Physical and working properties of the powders

Item	Powder (commercial name)	Particle size (1), μm	Apparent density, g/cm^3	Tap density, g/cm^3	Producer
1	Co (*Co SMS*)	1.0	0.7	1.3	Umicore (Belgium)
2	Co (*Co Extrafine*)	1.5	1.1	2.2	Umicore (Belgium)
3	Co (*Co 400mesh*)	4.1	1.5	2.4	Umicore (Belgium)
4	Fe (*Fe CN*)	6.9	3.6	–	Foxmet (Luxembourg)
5	W (*WP30*)	2.6	3.2	6.0	Eurotungstene (France)

(1) – measured with a Fisher sub-sieve sizer

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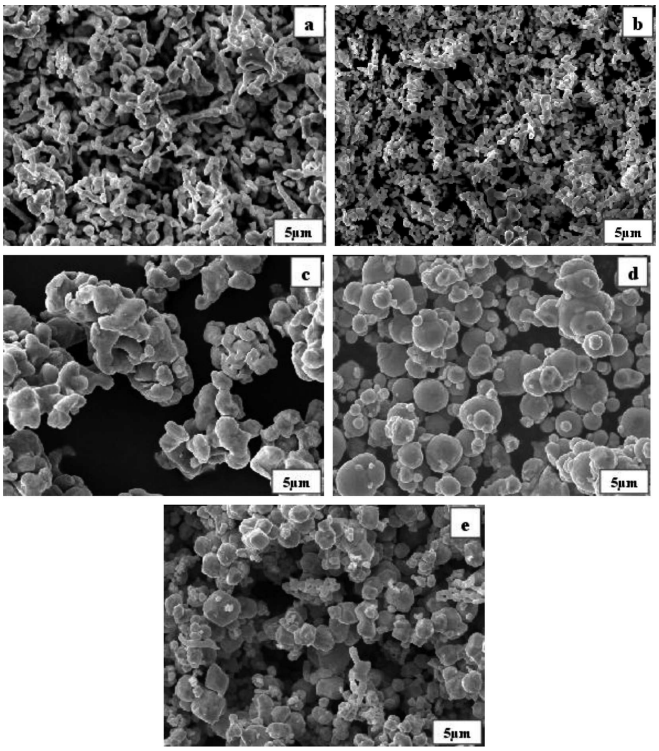

Fig. 1. Powders used in the analysis: a) *Co SMS*, b) *Co Extrafine*, c) *Co 400mesh*, d) *Fe CN*, e) *WP30*

simultaneous fabrication of ten samples with nominal dimensions of ~7×6×40 mm. All the analyzed powders were hot pressed for 2 minutes at maximum temperature and pressure. In this case, the pressure remained at 35÷40 MPa, due to limited strength of the graphite die. The temperature of the pressing process was adjusted individually according to the content so that the porosity of the sinters was not more than 5%. Hot pressing was performed at an atmosphere of nitrogen using an AGRA CAR1001 hot press furnace.

The content of the sinters and the parameters of the hot pressing process are shown in Table 2.

All the sinters were measured for density and hardness. The density was determined by weighing the samples first in air and then in water. Their hardness was established at a load of 10kG using the Vicker's hardness test method.

TABLE 2
The content of the materials analyzed and the parameters of the hot pressing process

Material	Content	Hot pressing parameters
Co (SMS)	100% Co SMS	850°C/35MPa/2min
Co (EF)	100% Co Extrafine	850°C/35MPa/2min
Co (400)	100% Co 400 mesh	950°C/35MPa/2min
CoFe (SMS)	50% Fe CN 50% Co SMS	900°C/35MPa/2min
CoFe (EF)	50% Fe CN 50% Co Extrafine	900°C/35MPa/2min
CoW (EF)	80% Co Extrafine 20% WP30	980°C/40MPa/2min
CoFeW (EF)	40% Fe CN 40% Co Extrafine 20% WP30	980°C/40MPa/2min

The measurement results are provided in Table 3.

TABLE 3
Density and hardness of the sinters

Material	Density [(1)], g/cm^3	Hardness [(1)], HV10
Co (SMS)	8.74±0.08	244±31
Co (EF)	8.73±0.01	271±4
Co (400)	8.72±0.01	254±7
CoFe (SMS)	8.10±0.01	248±18
CoFe (EF)	8.11±0.05	254±2
CoW (EF)	9.73±0.08	349±5
CoFeW (EF)	8.84±0.09	351±7

[(1)] the confidence intrevals were estimated for a confidence level of 0.95

Two samples were randomly selected to represent each sinter. Then, they were machined into non-standard samples to be used for static tensile strength tests. Their shape and dimensions are presented in Fig. 2.

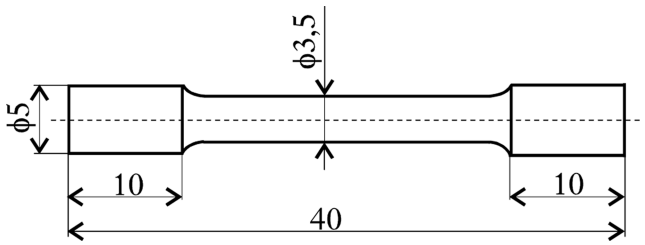

Fig. 2. Dimensions of the samples used in tensile strength tests

The tests were conducted at a traverse speed of 0.5 mm/min using a universal testing machine (INSTRON 4502) equipped with a data acquisition computer system. The sample elongation was registered with an extensometer along a measuring length of 10 mm. The experimental data were then used to calculate tensile strenth R_m, offset yield point $R_{0.2}$ and elongation $\Delta L/L$.

The test results are shown in Table 4.

TABLE 4
Results of the static tensile strength test (average values from three measurements)

Material No	Symbol	R_m, MPa	$R_{0.2}$, MPa	$\Delta L/L$, %
1	Co (SMS)	865	405	19.5
2	Co (EF)	954	634	9.5
3	Co (400)	743	540	1.7
4	CoFe (SMS)	515	498	0.9
5	CoFe (EF)	527	494	1.3
6	CoW (EF)	927	632	1.4
7	CoFeW (EF)	762	721	0.7

Some of the stress-strain curves, typical of each material, are shown in Fig. 3.

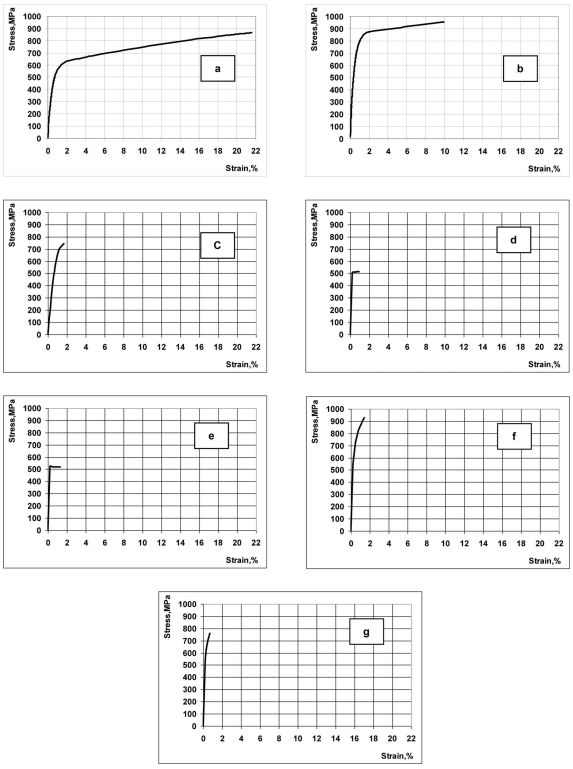

Fig. 3. Stress-strain curves obtained for: a) Co (SMS), b) Co (EF), c) Co (400), d) CoFe (SMS), e) CoFe (EF), f) CoW (EF) and g) CoFeW (EF)

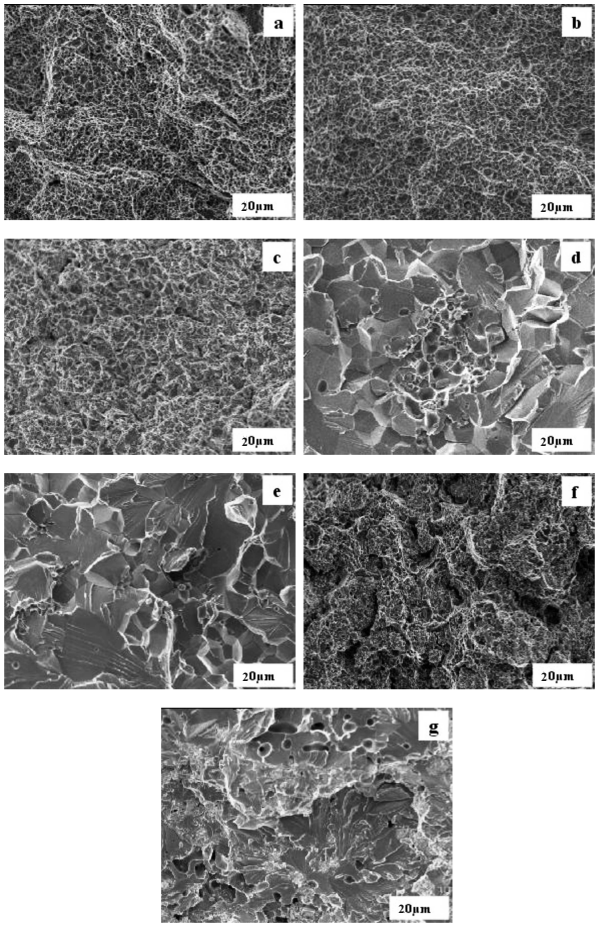

Fig. 4. Fracture surfaces after the tensile strength tests: a) Co (SMS) – No 1, b) Co (EF) – No 1, c) Co (400) – No 2, d) CoFe (SMS) – No 1, e) CoFe (EF) – No 2, f) CoW (EF) – No 2, g) CoFeW (EF) – No 2

After the tensile strength tests, the samples were analyzed using a Jeol JSM-5400 scanning microscope and a Leica DM4000 light microscope in order to determine their fractography and microstructure, respectively.

The fracture surfaces of the materials are shown in Fig. 4, and their microstructure in Fig. 5.

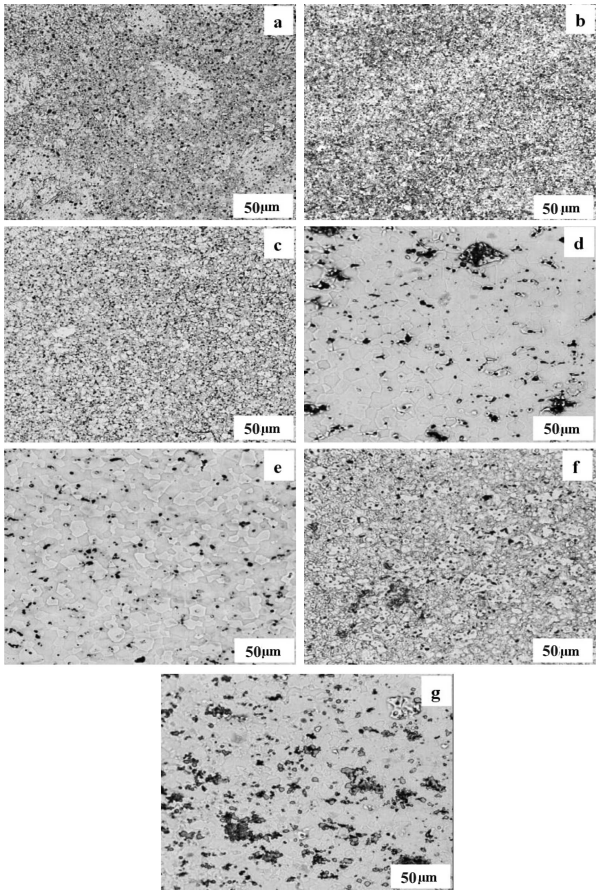

Fig. 5. Microstructure of the sinters: a) Co (SMS), b) Co (EF), c) Co (400), d) CoFe (SMS), e) CoFe (EF), f) CoW (EF) and g) CoFeW (EF). Etched with nital

3. Discussion and concluding remarks

The sinters produced by hot pressing at specified parameters were characterized by high density, similar to the theoretical density (Table 3). Replacing cobalt with iron did not affect the hardness of the sinters. The addition of tungsten (20% by mass), however, resulted in a substantial increase in the hardness of the materials (Table 3).

Sinters made from the *Co SMS* and *Co Extrafine* powders were found to have high tensile strength and high ductility (Table 4). Sinters made from the *Co Extrafine* powder possessed the highest yield strength at relatively small elongation.

Adding iron to cobalt led to a considerable decrease in the material yield strength. Previous studies on the structure of the Co-50%Fe sinters described in Refs. [12-13] show that the decrease in ductility was attributable to insufficiently rapid cooling of the material after hot pressing. A temperature lower than 730°C contributes to the formation of ordered iron solution in the α' cobalt matrix with B2 structure [14]. The analysis performed with a scanning electron microscope equipped

with an energy dispersive X-ray spectrometer (EDS) showed that the microstructure of the Co-50%Fe sinters comprised the α' superstructure and iron particles that were not completely molten [12-13]. After etching with nital, the particles underwent deep etching and that is why they are seen as pores distributed around the α' matrix (microphotographs 5d, 5e and 5g).

The addition of tungsten caused a nearly sevenfold reduction in the ductility of cobalt, whereas the addition of tungsten and iron resulted in a considerable increase in the yield strength of the sinters (Table 4).

The fractographic examination of the samples produced from Co and CoW (EF) powders (Figs. 4a, 4b, 4c and 4f) showed ductile dimpled fracture surfaces.

The fracture surfaces of the CoFe (SMS), CoFe (EF) and CoFeW (EF) sinters were mixed in nature, with brittle transcrystalline fracture being predominant (Figs. 4d, 4e and 4g).

Samples made from the *Co SMS* and *Co Extrafine* powders (Figs. 5a and 5b) had a microstructure with the finest grain size. The addition of iron resulted in a substantial growth of the sinter grains (Figs. 5d and 5e).

4. Conclusions

The following conclusions can be drawn from the present study:

1. Sinters produced from the *Co Extrafine* powder were found to have the highest tensile strength, high yield strength and good ductility.
2. Adding iron to cobalt (50% by mass) caused a nearly two-fold reduction in tensile strength and an over ten-fold decrease in the elongation of the sinters.
3. The addition of tungsten (20% by mass) to the powder mixture made the consolidation considerably more difficult. Producing sinters with low porosity (<5%) requires increasing the temperature and pressure of hot pressing to 980°C and 40 MPa, respectively.
4. Adding tungsten (20% by mass) to cobalt caused that the material hardness increased by ~30%. When tungsten was added to the mixture of cobalt and iron, the material hardness and yield strength increased to ~40% and ~45%, respectively.

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