Arch. Metall. Mater. **68** (2023), 4, 1579-1583

DOI: https://doi.org/10.24425/amm.2023.146225

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PROPERTIES OF FeCuSnNi SINTERS AS MATRICES OF METAL-DIAMOND COMPOSITES

The main purpose of the work was to determine the powder influence of the powder preparation on the microstructure and properties of iron-based sinters used as a metallic-diamond matrix. The sinters obtained from a mixture of comercial powders were used for research. A mixture of powders was selected for the tests, in which the mass fractions of individual powders were as follows: 60% Fe, 23.8% Cu, 4.2% Sn and 12% Ni. The powders were pre-mixed in a Turbula mixer and next a part of material was subjected to milling in a ball mill. Sintering was performed using hot-pressing technique in a graphite mould. The investigated properties of the sinters were concerned density, porosity, hardness, oxygen content, static tensile test and analysis of microstructure. Spot chemical analysis revealed the presence of Fe solution, Cu solution and the presence of iron oxides oxides. Nickel atoms were present throughout the sinter volume. The obtained test results showed that the presented sinter has good functional properties (hardness and thermal expansion) and can be used as a diamond-metal composite matrix in diamond tools.The microstructure and mechanical properties of sinters were investigated.

Keywords: Metallic matrix; powder metallurgy; diamond tools

1. Introduction

Diamond blades are commonly used for cutting natural stone and ceramics. The cutting section of the tools consists of synthetic diamonds embedded in a metallic matrix by powder metallurgy technology [1,2]. There are many metals which have been used as matrices of diamond impregnated tools. In general examples of such metals are cobalt, aluminium, titanium, copper, iron, zinc, tin and nickel. For the few years, the using of inexpensive powders pre-mixed and milled in ball mills, which may replace cobalt powders, is observed [3,4]. Diamond-metallic composites based on metal matrices containing iron, copper, nickel, and tin have a favorable mechanical properties, a relatively low sintering temperature and the low cost of materials [5-8].

On the basis of previous research [9], the iron-based material for matrix of metallic-diamond tools was designed. The material was obtained from elemental powders subjected to milling for 30 h. The material was selected for the tests, with the mass fractions of individual powders as follows: 60% Fe, 23.8% Cu, 4.2% Sn and 12% Ni. The new matrix material have a porosity not exceeding 3% as well as mechanical properties that would allow to replace cobalt-based sinters [10].

The very important role of a matrix in diamond impregnated segments is to hold diamond particles for as long as possible. The effective way to improve diamond retention in the matrix leads through using of the diamond particles with a thin film of strong carbide obtained with coatings technology .

2. Material and its mechanical properties

The experimental powder mixtures were made from the following elemental powders (Fig. 1):

a) NC100.24 grade, carbon-reduced iron powder (20-180 μm), from Höganäs Germany GmbH,
b) T255 grade, carbonyl nickel powder (average size = 2.4 μm), from Vale S.A. Brasil,
c) water-sprayed tin bronze powder containing 15% by mass. tin (25GR85/15.325 from ECKA Granules Germany GmbH), with a particle size below 45 μm.

Mass fractions of individual powders in the tested material FeCuSnNi were: 60% Fe, 28% bronze and 12% Ni, which corresponds to the chemical composition: 60% Fe, 23.8% Cu, 4.2% Sn, 12% Ni. Before the consolidation process, the powders were pre-mixed in the right proportions in a Turbula mixer

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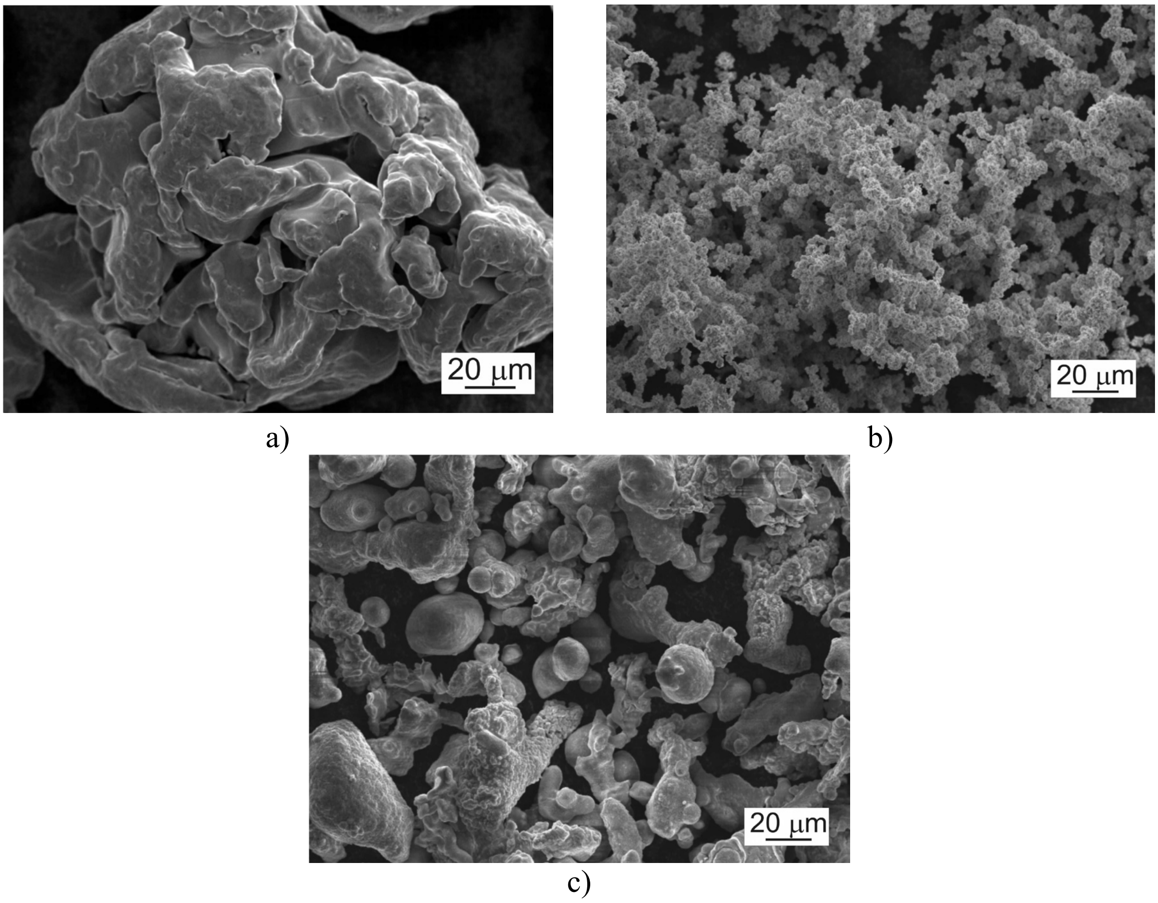


Fig. 1. Powders used for research, a) iron powder NC100.24, b) nickel powder T255, c) tin bronze powder 25GR85 / 15.325

for 30 minutes, and then milled in an EnviSense RJM-102 laboratory ball mill in ethyl alcohol with a small amount of glycerol. The milling vial was filled to half of its volume with 12 mm diameter 100Cr6 steel balls.

The initial mixtures of FeCuSnNi powders and ground powders of both materials were subjected to consolidation by hot pressing, in nitrogen atmosphere, using the Unidiamond press furnace – Idea (Italy), within 30 hours. The prepared mixtures were pressed in a graphite matrix, enabling the simultaneous production of 4 samples with nominal dimensions of 7×6×40 mm.

TABLE 1

Physical properties of the material

Material	**Density, [g/cm^3]**	**Porosity, [%]**	**HV10**	**Oxygen content, [% mas.]**
FeCuSnNi, without milling	8.000±0.028	2.20±0.20	241.7±15.4	0.34±0.03
FeCuSnNi, milling 30 h	8.008±0.037	2.20 ± 0.40	272.7±8.4	0.59±0.0

The static tensile test was carried out with the use of a universal testing machine UTS-100 with an automatic control and data recording system by Zwick. Based on the recorded data, the yield strength $R_{p0.2}$, the tensile strength R_m and the relative elongation ε have been calculated. The above-mentioned parameters were determined as the arithmetic mean of three tensile tests. The elastic modulus E and Poisson's ratio v were also measured by ultrasound using a Panametrics Epoch III flaw detector.

The sinters obtained from powders after milling show higher hardness and clearly tensile strength compared to sinters made of powders without milling.

TABLE 2

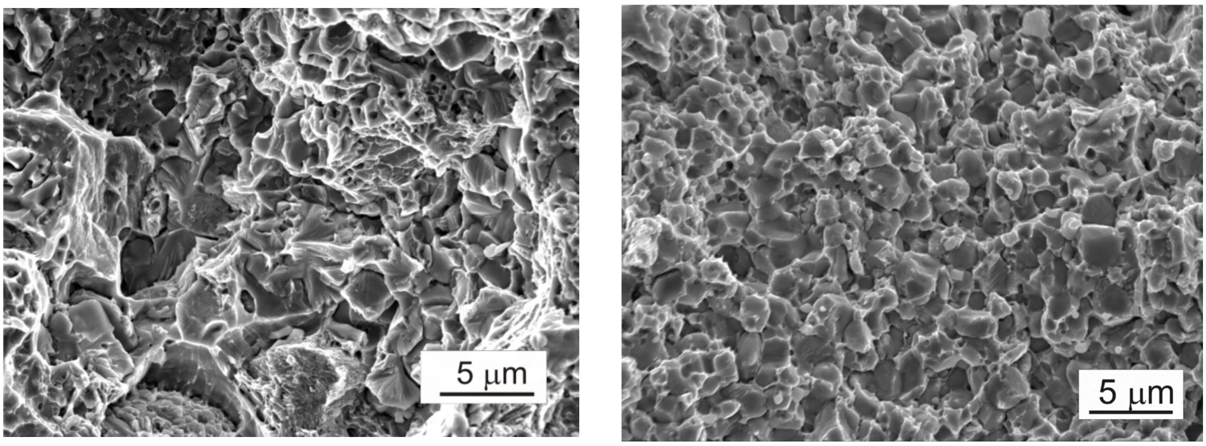
Mechanical properties of the material

Material	**Elastic modulus E [GPa]**	**Poisson ratio N**	**Yield strength $R_{p0.2}$ [MPa]**	**Tensile strength R_m [MPa]**	**Relative elongation ε [%]**
without milling	—	—	169±10	481.1±15.6	7.5±0.2
milling 30 h	165±3	0.32	273±12	739.4±20.5	11.0±0.5

3. Fractography of fracture

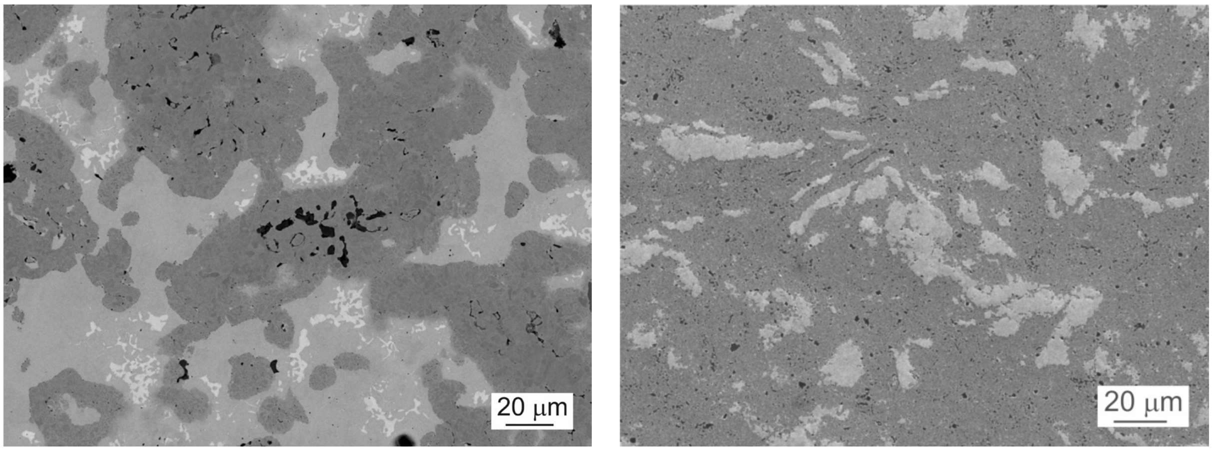
Fractographic tests were carried out on the fracture obtained in the tensile test. The research was carried out using the JSM-7100F scanning electron microscope, integrated with the OINA-AZtec X-ray microanalysis system.

Observations of the fracture surfaces lead to the conclusion that for all sinters of the tested materials without milling,



a) b)

Fig. 2. Surface fracture of FeCuSnNi sinter samples obtained from powders a) without milling, b) after milling for 30 h



a) b)

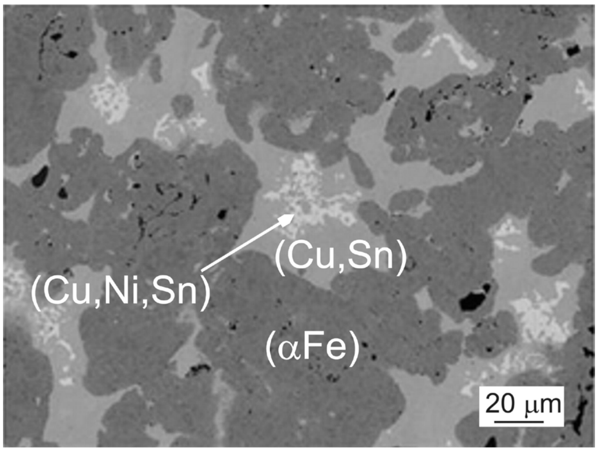
Fig. 3. Microstructure of sinters made of FeCuSnNi powder, a) not subjected to the milling process, b) subjected to milling for 30 h

the fracture is brittle and transcrystalline. Cracking is initiated at the grain boundaries. The mechanism of fracture is mixed. On the other hand, for sinters made of powder mixtures, after a grinding time of 30 h, there is a developed fracture surface. The fractures take a ductile form, only areas showing the features of an intercrystalline fracture are visible in places.

4. Microstructure studies

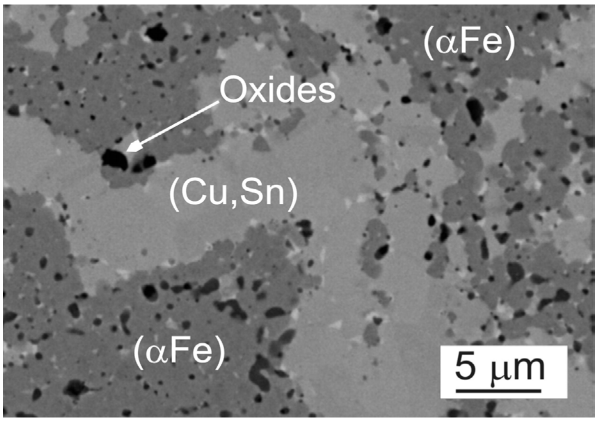
The observations of the microstructure of the produced sinters were carried out using the JSM-7100F scanning electron microscope, integrated with the X-Max-AZtec series EDS microanalysis system from OXFORD INSTRUMENTS. The tests were carried out using a detector of backscattered electrons. The microstructure of FeCuSnNi sinters, obtained from powder mixtures without milling and after milling 30 h, was presented at a magnification of 500× (Fig. 3).

The FeCuSnNi sinter revealed a complex phase structure (Fig. 4). Point chemical analysis showed the presence of Fe solution, Cu solution and iron oxides (Fig. 5). The nickel atoms were



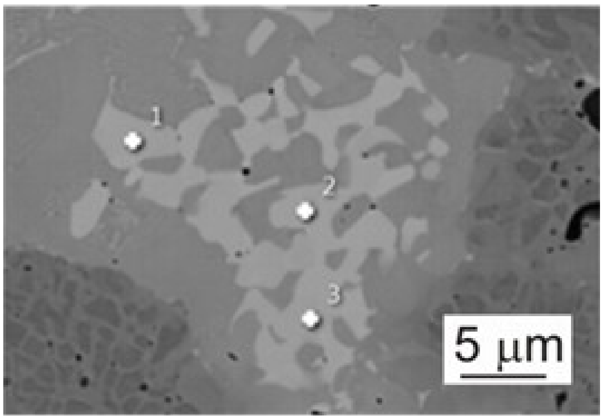
	O [%]	Fe [%]	Cu [%]	Sn [%]	Ni [%]
(Fe)		85.73	4.56	0.34	9.37
(Cu)		3.26	85.55	5.65	5.54
Oxides	15.12	72.64	3.33	2.05	6.86

Fig. 4. Microstructure of the FeCuSnNi sinter (without milling), the results of the microanalysis (wt%) with the spectra of X-rays collected from the areas: Fe solution, Cu solution and in the white area of iron oxides



	O [%]	**Fe [%]**	**Cu [%]**	**Sn [%]**	**Ni [%]**
(Fe)	—	72.59	10.54	0.93	15.94
(Cu)	—	5.24	78.04	11.32	5.40
Oxides	17.18	71.64	1.97	0.75	8.46

Fig. 5. Microstructure of the FeCuSnNi sinter (milling 30 h), the results of the microanalysis (wt%) with the spectra of X-rays collected from the areas: Fe solution, Cu solution and the area of iron oxides



	Fe [%]	Cu [%]	Sn [%]	Ni [%]
1	1.59	28.20	38.47	31.74
2	2.04	29.28	36.03	32.65
3	2.30	26.17	38.09	33.44

Fig. 6. Microstructure of the FeCuSnNi sinter (without milling) with the point chemical composition

distributed throughout the entire sinter volume with a distinct advantage in the white phase (Fig. 6) [11]. The oxides concentrated in the region of the iron solution. For FeCuSnNi sinters obtained from powders without milling and after 30 h of milling, point chemical composition and surface distribution of elements are shown in the Figs. 4-7.

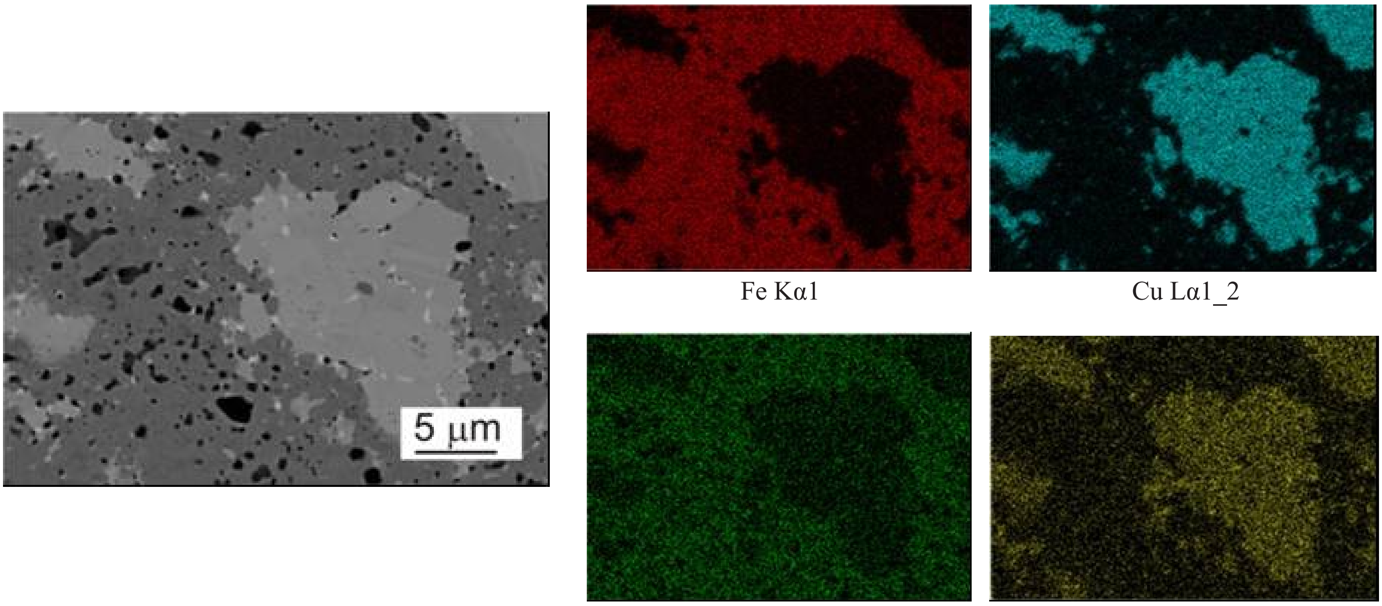
In the area rich in iron, there are also Ni atoms, which easily integrate into the network of Fe atoms because nitrogen has similar sizes of atomic radii.

Additionally, a detailed point analysis of the chemical composition of the area in white was performed. The conducted analysis showed the presence of an intermetallic relationship of copper, nickel and tin.

5. Conclusions

The research shows that the milling causes a greater homogenous elements distribution for tested materials. The microstructure of the sinter obtained from mixtures without milling, also after 30 hours of milling, is heterogeneous – large areas of iron solution are noticeable in it, in which greater amounts of nickel were found. Hence, it can be concluded that nickel diffusion proceeds into the iron solution.

The microstructures of the sinters obtained from the mixes milled through 30 h show distinctive features. There is a banding and lamellar shape which is due to the flake shape of the powder particles. In the microstructure of the FeCuSnNi alloy made of an



Fe Kα1
Cu Lα1_2
Ni Kα1
Sn Lα1

Fig. 7. Surface distribution of elements in the FeCuSnNi sinter, obtained from powder mixtures after milling for 30 h

unground powder mixture, there is a white phase which clearly decreases after 30 h grinding. A point analysis of the chemical composition of this phase showed a high concentration of copper, tin and nickel. The analysis of the chemical composition shows that it is the intermetallic phase $(CuNi)_3Sn$. In the milling process, nickel is dissolved in bronze and tin diffuses into the iron solution. The introduction of a tin bronze addition, instead of copper, to Fe and Ni powders, resulted in obtaining a liquid phase (>798°C) during the hot pressing process, which helped to consolidate and intensify diffusion of phase components.

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