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THE MICROSTRUCTURE AND PROPERTIES OF HOT PRESSED IRON BRONZE POWDERS

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Abstract

This paper reports on the results of a study of the mechanical properties of sinters made of a new iron-based material, which is becoming increasingly popular in the manufacture of diamond impregnated tools as an economical substitute for cobalt and cobalt alloys. The sinters were formed by hot pressing a mixture of iron and bronze powders. Their properties were compared with those of hot pressed cobalt SMS powder. The specimens were analyzed for density, porosity, hardness, expansion and tensile strength. The fracture surface topography and the material microstructure were analyzed with an electron scanning microscope and a light microscope. The study involved determining the effects of the content of the powder on the chemical composition of the sinters as well as the influence of the fabrication process on the microstructure and mechanical properties of the material. The investigations show that the new iron-based material is inferior to cobalt; however, because of a favourable combination of hardness, yield strength and ductility it seems suitable for general purpose applications.

Keywords: bronze, iron, hot pressing, sintered diamond tools, matrix powder

1. INTRODUCTION

Research and development activities of the tools industry include searching for a new material to replace cobalt used as the matrix in diamond impregnated tools for cutting natural stone and other building materials. Cobalt powders are still the best material for the matrix of metal-diamond composites. After hot pressing at a temperature of 750÷950°C, they form sinters characterized by low total porosity and high resistance to abrasive wear [1]. The cobalt matrix has very good retention properties that allow diamond particles to adhere; the particles are kept in the matrix by mechanical and/or chemical bonds [2-8]. Historically, cobalt has been and still is the most popular material. However, its high and unstable price [1] results in a high total cost of tools [1-4]. Moreover, cobalt is not harmless to human health. As it may cause allergic reactions [9], producers of metal-matrix diamond tools are looking for ways to replace cobalt powders with powders that are cheaper, neutral to the human body, and with performance properties similar to those of cobalt to produce tools at lower manufacturing costs [6,9,10].

Currently, investigations focus on the application of cheap iron powders as the metal matrix [11]. Fine carbonyl iron powders seem the most suitable to produce premixes [12]. Producers of metal powders from Europe and the Far East (e.g. China) use the most advanced technologies to prepare press-ready premix powders for producing metal-matrix diamond tools [8]**.** The major benefits of such powders are a reasonable price, ease of consolidation by hot pressing and possibility to impart vastly different strengths and plastic properties by selecting the right temperature of hot pressing. Because of their attractive price, premix powders are becoming increasingly popular with producers of metal-diamond tools. They are replacing powders obtained with traditional methods. Theoretical and experimental investigations are being conducted to determine whether iron-based powders can be used to produce iron-matrix diamond composites with additives of copper, zinc, and tin [11,13] and become an economical substitute for cobalt powders to produce disc saws for cutting natural stone [11].

This study involved analyzing a commercial iron-based powder mixture called CSA800. According to the information on its laboratory and experimental use provided by the Chinese producer [14], the powder is universal and can be directly used to manufacture diamond impregnated tools for cutting various stones and ceramics.

The paper studies the influence of the chemical composition and the fabrication process on the microstructure and mechanical properties of sinters obtained from the CSA800 powder. The properties of the sinters were compared with the properties of hot-pressed sinters produced from SMS cobalt powder [13,15,16].

2. MATERIALS AND METHOD

The investigations were conducted on sinters obtained by hot pressing from the following powders:
a) iron-based powder (CSA800) provided by a Chinese supplier to be used in laboratory and experimental testing,
b) cobalt powder (SMS) with a particle size of 1.0 μm, according to the Fisher scale; produced by a Belgian company, UMICORE; with a mass percentage composition of ≥ 99.7 % Co.
The shapes and arrangement of the powder particles used in the study are shown in Fig. 1.

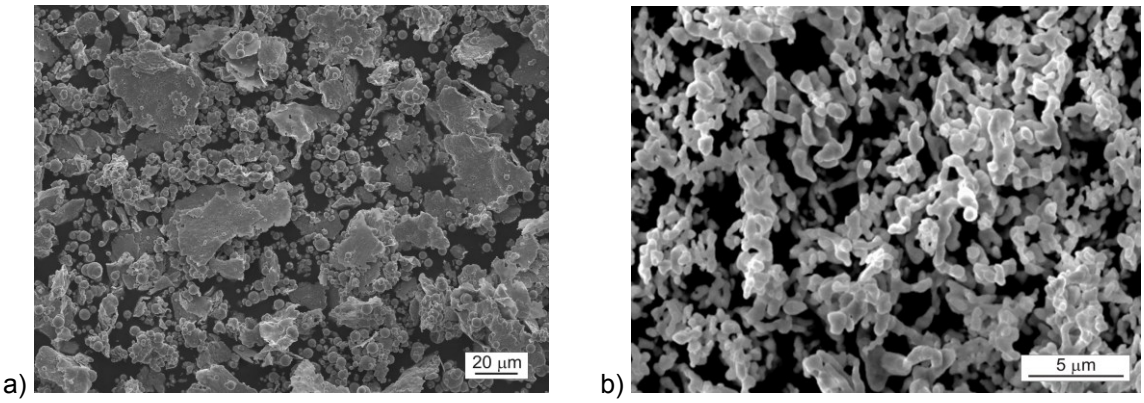

Fig. 1 SEM micrograph of the (a) CSA800 and (b) Co(SMS) particles

Before consolidation, the CSA and Co(SMS) powders were tested and analyzed with a JSM-7100F scanning electron microscope integrated with an OINA-AZtec EDXS microanalysis system. As suggested by the suppliers, the powders were then consolidated by hot pressing in a graphite mould. Ten samples with nominal dimensions ~7x6x40 mm were produced simultaneously. The powder mixtures were held for 3 minutes at a maximum temperature of 880°C and a pressure of 35 MPa. The hot pressing process was performed in the atmosphere of nitrogen using an ARGA CAR1001 hot press furnace. All the sinters were measured for density and hardness. The density was established by weighing in air and water with WPA120 type hydrostatic scales. The density data was used to determine the porosity of the sinters. The hardness of the sinters was measured at a load of 10 kG using the Vickers method. The measurement results are presented in Table 1.

Table 1 Density and Vickers hardness of the as-hot pressed samples

Powder	Hot pressing conditions	Density [g/cm^3]*	Theoretical density [g/cm^3]	Porosity	HV10
CSA800	880°C/35 MPa/3 min	8.13 ± 0.02	8.34	2.57%	223 ± 12
Co(SMS)	850°C/35 MPa/3 min	8.74 ± 0.04	8.90	1.80%	271 ± 3

* scatter intervals estimated at 90% confidence level

The strength tests were conducted using an INSTRON 4502 universal testing machine. The crosshead rate was set to be 0.5 mm/min and the diameter of the gauge section was 3.5 mm. The elongation was registered by means of an extensometer with a gauge length of 10 mm. The test results were used to calculate the offset yield strength $R_{0.2,}$ the ultimate tensile strength R_m, and the relative elongation ε. The stress-strain curves plotted for CSA800 and Co(SMS) are shown in Fig. 2. Table 2 compares the test results for CSA800 with those obtained for cobalt.

Table 2 Results of the static tensile test

Material	Modulus of elasticity E* [GPa]	Offset yeild strength $R_{0.2}$ [MPa]	Ultimate tensile strength R_m [MPa]	Maximum elongation ε [%]
CSA800	158	405.0 +/- 31.2	591.0 +/- 14.6	3.47% +/- 0.28%
Co(SMS)	205	404.5 +/- 25.4	865.0 +/- 12.0	19.5% +/- 1.5%

* determined using the acoustic method

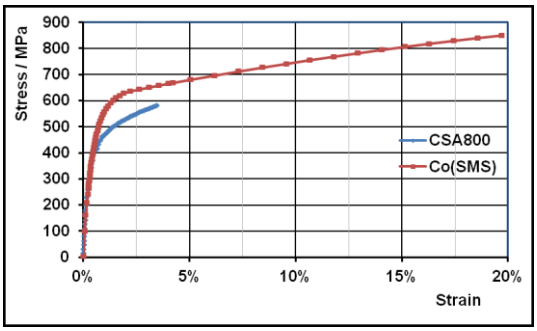

Fig. 2 Comparison of the tensile strength curves for the CSA800 and Co(SMS) sinters.

Dilatometry was used to monitor the occurrence of phase transitions in the analyzed sinters when heated up to 900°C and cooled to room temeprature. The results are presented in Fig. 3.

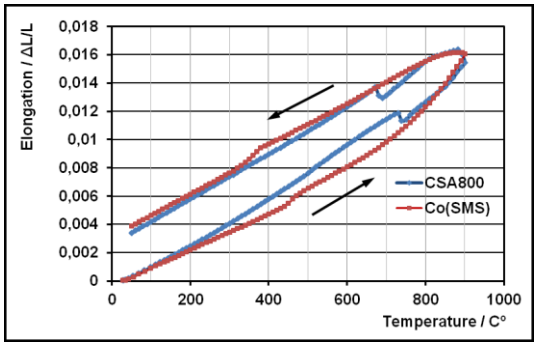

Fig. 3 Dimensional changes in the CSA800 and Co(SMS) sinters detected by dilatometry

The tensile specimens were examined by fractography using a JSM-7100F scanning electron microscope integrated with an OINA-AZtec system for EDX spectroscopy.

Figure 4 illustrates the character of the fractures of the materials studied. The microstructure of the CSA800 sinter and example EDS spectra for the particular phases are shown in Fig. 5.

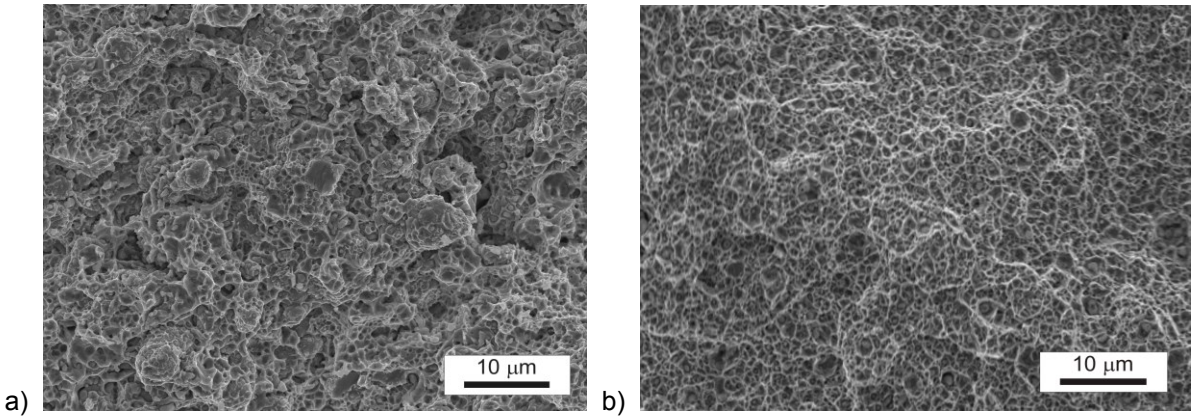

Fig. 4 Scanning electron fractograph of the tensile strength specimens: a) CSA800, b) Co(SMS)

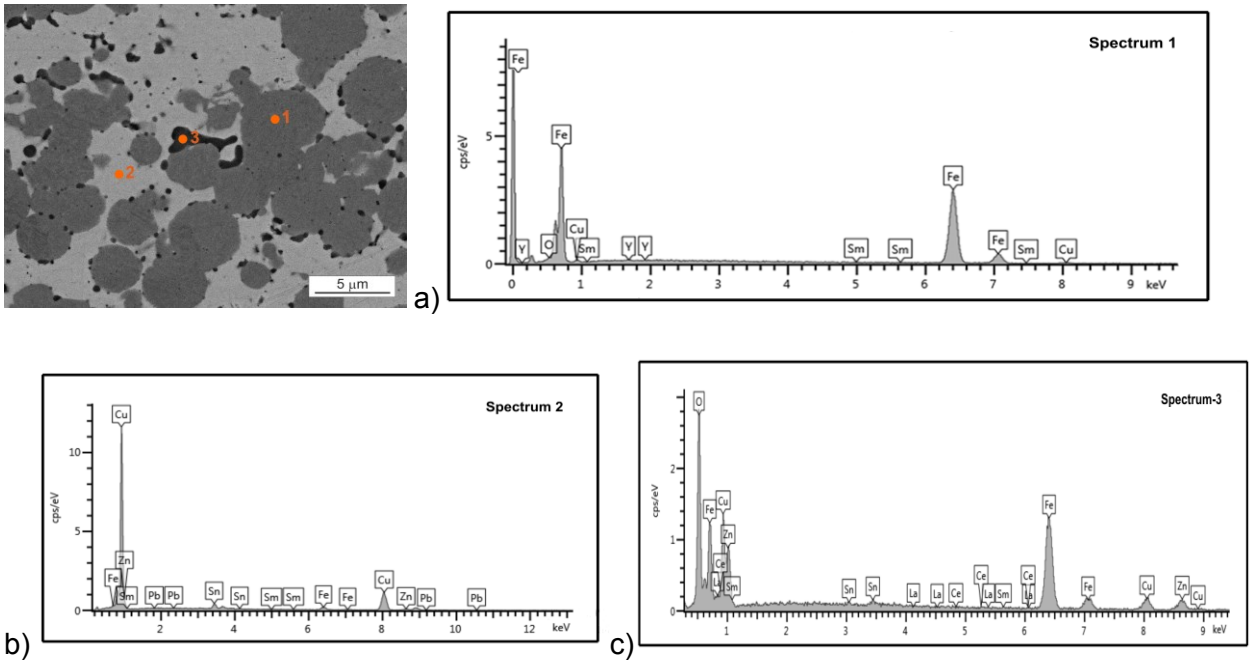

Fig. 5 Microstructure of the CSA800 sinter with the X-ray spectra for the particular phases

Table 3 shows the chemical composition in weight percent obtained from the EDS analysis. The spectra 1, 2 and 3 correspond to points 1, 2 and 3 marked in the microstructure in Fig 5.

Table 3 Chemical composition of the phases

Weight %	O	Fe	Cu	Zn	Sn	Sm	Pb	Y	La	Ce	Total
Spectrum 1	0.68	94.76	3.09	0.00	0.00	1.21	0.00	0.27	0.00	0.00	100%
Spectrum 2	0.00	4.17	82.09	7.20	6.09	0.18	0.28	0.00	0.00	0.00	100%
Spectrum 3	16.66	42.23	22.84	16.57	0.97	0.22	0.15	0.00	0.14	0.21	100%

3. DISCUSSION AND CONCLUSIONS

The EDS analysis (Fig. 1) shows that the powder is composed of non-purified iron carbonyl particles mixed with irregular much coarser particles of the initially alloyed bronze. The spectra obtained for the particular particles indicate that bronze contained up to 6% Zn, 3% Sn and 1% Pb. The analysis of the CSA800

powder particles suggests that it is a mixture of carbonyl iron and bronze particles (B663) containing about 6% Zn, 6% Sn and 3 % Pb. The powders constituting the sintering mixture were used in almost equal proportions.

As shown in Table 1, the CSA800 alloy exhibits an interesting combination of mechanical properties. It has high hardness (223 HV10), high tensile strength (591 MPa) and high offset yield strength (404 MPa) at a maximum elongation of 3.3 %. The fractographic examinations show that the fractures are ductile and dimple in character.

Compared with cobalt, CSA800 has worse strength parameters. It should be emphasized, however, that its hardness, yield strength and ultimate tensile strength are sufficiently high to make the material suitable for general-purpose tools with less demanding applications [4,3].

The dilatometry curve in Fig. 3 confirms the presence of carbon impurities in carbonyl iron in the CSA800 powder, which corresponds to the occurrence of the eutectoid reaction in the curve. From Fig. 3 it is evident that the CSA800 alloy begins swelling when heated at a temperature of above 740°C and this is most probably due to the partial melting of the bronze constituent. The alloy solidifies completely after cooling at a temperature of below 700°C. Hot pressing of the CSA800 powder at a temperature higher than 740°C seems favourable because the occurrence of the liquid phase results in higher consolidation.

The dilatometry curve obtained for Co(SMS) (Fig. 3) is non-linear at a temperature of 423 °C during heating and cooling. There is a clear relationship between the points and the phase transition of cobalt from a hexagonal crystal structure (A3) during heating at a temperature higher than 417°C into a regular side-centered structure (A1); the opposite was observed during cooling.

The metallographic specimens of the CSA800 sinters were analyzed using energy dispersive spectroscopy. The data confirms that the complex multi-phase microstructure contains 42-57%wt Fe, 35-51% Cu, 3-4% Zn, 3% Sn, <1% Pb, and trace amounts of rare earth metals.

As can be seen from Fig. 5, the alloy consists of a solution (α-Fe) rich in carbon - (point 1 in Fig. 5), a solution of copper (Cu) - (point 2 in Fig. 5), which is a solid solution of Sn and Zn in Cu, and dark areas being a mixture of metal oxides - (point 3 in Fig. 5). Despite the occurrence of peaks of Pb in the EDS spectrum, there are no isolated inclusions of Pb in the structure.

It can thus be concluded that the CSA800 material is worth considering beacuse of its reasonable price, ease of consolidation by hot pressing and ability to modify its strength and plastic properties by modifying the temperature of hot pressing. Alloys containing CSA 800 reach >97 % of the theoretical density after as short a holding time as 3 minutes at a pressure of 35 MPa and a temparature of 800-880°C. The consolidation of the CSA800 powder mixture used as the matrix material and the diamond powder at a temperature of above 900°C may reduce the strength of the diamond particles. Thus, hot pressing at a temperature of 880°C minimizes the negative effect of high temperatures on the strength of diamond. Even though CSA800 has worse mechanical parameters than Co(SMS), it can be used in general-purpose tools with less demanding applications.

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