JAMME
Journal
of Achievements in Materials and Manufacturing Engineering
International Scientific Journal
published monthly by the
World Academy of Materials
and Manufacturing Engineering

The comparison of the sintering methods for diamond cutting tools

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ABSTRACT

Purpose: Aim of this study is to compare mechanical, physical, microstructural properties of diamond cutting tools (DCTs) made of Co-Ni-Cu-Sn matrix, produced by Spark Plasma Sintering (SPS) and Conventional Sintering (CS) methods. The main reason for this research is choosing the most convenient and economically manufacturing method for diamond cutting tools.

Design/methodology/approach: Aim of this study is to compare mechanical, physical, microstructural properties of diamond cutting tools (DCTs) made of Co-Ni-Cu-Sn matrix, produced by Spark Plasma Sintering (SPS) and Conventional Sintering (CS) methods. The main reason for this research is choosing the most convenient and economically manufacturing method for diamond cutting tools.

Findings: The results showed that, the density values of the samples which are produced two different sintering methods are similar. However, the mechanical and microstructure properties of the samples which are produced by SPS method are decent. The robust mechanical properties were obtained at SPS method than CS method.

Practical implications: Powder metallurgy is the most common method because of forming new diamond grains due to wearing of matrix. In powder metallurgy, Conventional Sintering (CS) and Spark Plasma Sintering (SPS) are used at DCTs production prevalently. SPS is a short and effective way to produce diamond tools but costs are higher and production capacity is lower than conventional sintering method.

Originality/value: This paper demonstrates that the sintering methods can effect the cutting performances of the DCTs. The samples which are produced with CS method had elevated cutting performance on-site field tests.

Keywords: Diamond cutting tools; Natural stone; Cutting process; Powder metallurgy; Sintering methods

Reference to this paper should be given in the following way:

B. Bulut, O. Tazegul, M. Baydogan, E.S. Kayali, The comparison of the sintering methods for diamond cutting tools, Journal of Achievements in Materials and Manufacturing Engineering 76/1 (2016) 30-35.

MANUFACTURING AND PROCESSING

1. Introduction

Diamond is chemically pure carbon with a body-centered, cubic crystalline structure and it is the hardest substance known naturally occurring [1]. Diamond has many outstanding properties beside high hardness, great toughness, high thermal conductivity, low friction and high wear resistance [2]. Therefore diamond is exceptionally suitable for grinding or cutting of very hard materials such as hard metals, glass, natural stone and concrete [3,4]. Metal matrix-impregnated diamond materials, produced with diamond grits imbedded in a metal matrix, are widely used in diamond tools fabrication for cutting, grinding, drilling, and polishing natural stones [5,6]. Processing of diamond in metal bonds often results in a reaction between the diamond surface and the surrounding metal matrix [7,8]. The extent of this reaction depends upon the specific composition of metal powders, their particle size and distribution, the processing temperature and time [9].

The performances of diamond cutting tools (DCTs) depend on the diamond-holding ability and the wear resistance of the matrix [10,11]. Number of operating conditions such as feed rate, depth of cut, peripheral speed, load, pressure, velocity, cutting mode, properties of rock, working conditions etc. governs the wear rate of DCTs [12]. For this reason, it is very important to choose right matrix material in the manufacturing process of DCTs. Depending on the properties of the natural stone (its hardness and abrasivity), the metal matrix contains the metals or alloys as follows: iron, cobalt, cobalt and tin, cobalt and bronze, tungsten carbide [13,14].

Sintering method is another issue which determines the properties and performances of DCTs. DCTs can be produced by different types of methods such as electroplating, powder metallurgy and brazing [15,16]. Hot Isostatic Pressing (HIP), Spark Plazma Sintering (SPS), Conventional Sintering (Pressureless sintering) methods are widely used by the manufacturers in powder metallurgy methods [17]. HIP can be implemented after conventional sintering to increase density of matrix and close the pores in the structure. SPS is a short and effective way to produce diamond tools but costs are higher and production capacity is lower than conventional sintering method [18,19].

There are a number of studies that have investigated the sintering effect on the diamond cutting tools. Xie et al. [20] had analyzed the expansion ratio, linear shrinkage, densification rate and effect of heating rate on the sintering of Fe-Co-Cu pre-alloyed powders in the pressureless sintering. They concluded that the samples with higher Cu content had the more obvious expansion and with the Fe content increasing, the linear shrinkage beginning temperature and maximum densification rate corresponding temperature became lower. Also they indicated that the activation energy in the initial stage was larger than that in the final stage. Selvi et al [17] studied conventional sintering of diamond cutting tools. They compared microstructural, physical and mechanical properties of diamond cutting tools made of Co based metal matrix, produced by Spark Plasma Sintering and Conventional Sintering (CS). Spark Plasma Sintering performed at 850°C and Conventional Sintering performed at various temperatures (between 950 and 1150°C) and times (1 to 4 hours). They determined the optimal sintering temperature and time for conventional sintering as 950°C and 3 h. They concluded that mainly the same phases are observed in CS and SPS samples, the density and the hardness values of the CS method couldn't reach the SPS method. Chung et al. [21] had studied about diamond/Cu composites fabricated via pressureless sintering. They mixed the diamond, copper and titanium powders by mechanical and compacted at 700 MPa, and then sintered in tube furnace with H_2. They were successfully fabricated Diamond/Cu-Ti composites with high thermal conductivities via pressureless sintering method without impurities. They mentioned that applying pressureless sintering method to fabricate high thermal conductive composites provides an easier and more cost-effective alternative method to produce diamond/Cu-Ti composites with high thermal conductivities.

Aim of this study is to compare mechanical, physical, microstructural properties of DCTs made of Co-Ni-Cu-Sn matrix, produced by SPS and CS methods.

2. Material and experimental methodology

2.1. Materials

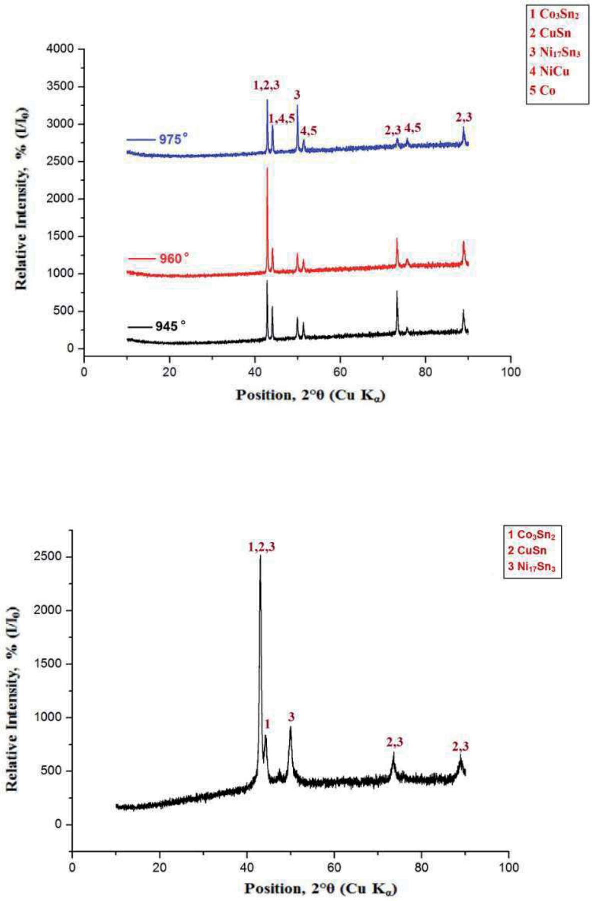
The Bronze based prealloyed powder was prepared as the sintering samples. The powder compositions are 60% vol Bronz, 30% vol Co and 10% vol Ni. The metal powder was mixed in 360° rotating chamber for 3 h. The powder mixtures were compacted in a cylindrical shape (7 mm in diameter and 14 mm in length) with an uniaxial cold press by the application of 50 kN force. Conventional Sintering (CS) was performed in a continuous tunnel furnace at three different temperatures (945, 960 and 975°C) under hydrogen atmosphere for 1 h. At the same time, Spark Plazma Sintering (SPS) was performed at 900°C with 238 bar pressure.

2.2. Characterization techniques and mechanical tests

Density measurements, hardness and compression tests were performed for physical and mechanical characterization of the samples. Density of the samples was determined by the Archimedes method and divided by the theoretical density to calculate the relative density. Hardness measurements were performed in the Rockwell B scale by using Zwick/Roell ZHR hardness tester and the compression tests were carried out using Dartec universal testing machine at a crosshead speed of 1 mm/min. X-ray diffraction (XRD) analysis was used for quantitative identification of the phases by a Bruker D8-Advanced X-ray diffractometer using Cu Kα radiation. Microstructures of the samples were examined by a HITACHI TM-1000 Tabletop Scanning Electron Microscope (SEM) equipped with an EDS (Energy Dispersive Spectroscopy) unit. Abrasion wear tests were conducted in a DVT DA6 model abrasion tester. The samples were vertically installed in the rotary table of the tester which is covered with 80 grade sandpaper. The table was rotated with 40 rpm and 1 kg vertical load was applied on the processed composites. The composites were moved on the table for 20 m and samples were weighted before and after the wear test. Relative wear resistance was calculated as the ratio the maximum weight loss over the sample's weight loss. According to this definition, the relative wear resistance of the maximum weight loss specimen is 1.

3. Results

Various experiment were performed to determine the most suitable sintering method for DCTs. XRD analysis results of investigated samples which are sintered with CS and SPS methods are given in Figure 1 (a) and 1 (b), respectively. The identified phases for studied samples which were sintered at different temperature by CS method are same. The obtained phases are Co_3Sn_2 intermetallic phase, CuSn, $Ni_{17}Sn_3$, NiCu and pure Co. The peak intensities of Co_3Sn_2 at CS samples sintered at 960 ° are higher than the samples sintered at 945 and 975°. The product phases for samples were sintered by SPS method are mainly same with CS method. The obtained phases are Co_3Sn_2 intermetallic phase, CuSn, $Ni_{17}Sn_{3.}$ Another important observation on XRD patterns is that the peak intensities of the Co_3Sn_2 intermetallic phase at SPS method are higher than CS method. Fig 2 (a) shows SEM micrographs and Fig. 2 (b) shows EDS analysis results of the samples investigated sintered by SPS method. Fig. 3 (a-c) shows SEM micrographs and Fig. 3 (d-f) shows the corresponding EDS patterns of the samples investigated sintered at different temperature by CS method. Different colored regions observed in SEM images of the samples which are given in Figures 2 and 3 show different phases. According to the EDS analyses, white phase contains more bronze elements (Cu and Sn), grey phase contains more Co than the other elements and black regions represent the porosities in the microstructure. The lowest porosity was observed at samples sintered with SPS method. Among the samples sintered with CS method, the lowest porosity was observed at samples sintered at 960°C.


a)

b)

Fig. 1. XRD analysis of the samples sintered (a) CS method and (b) SPS method

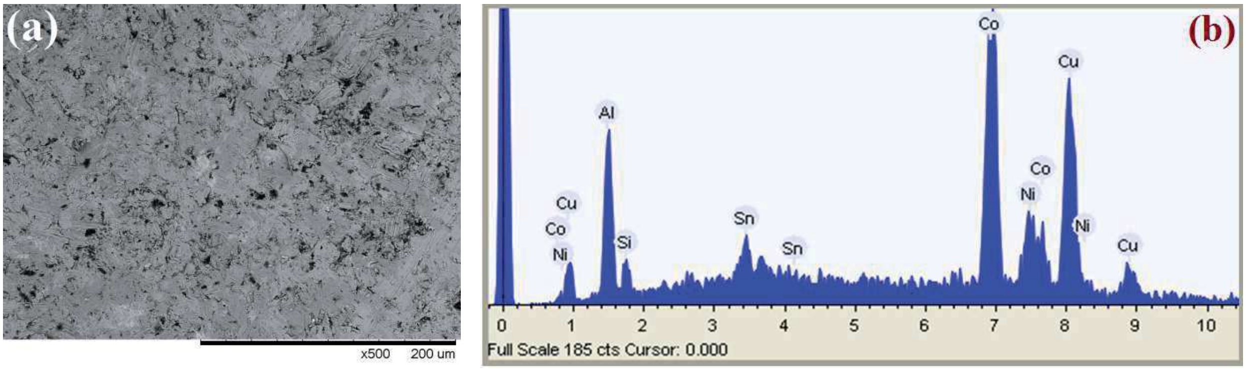


Fig. 2. (a) SEM Microstructures of the sample sintered with SPS method and (b) corresponding EDS analysis of the sintered sample

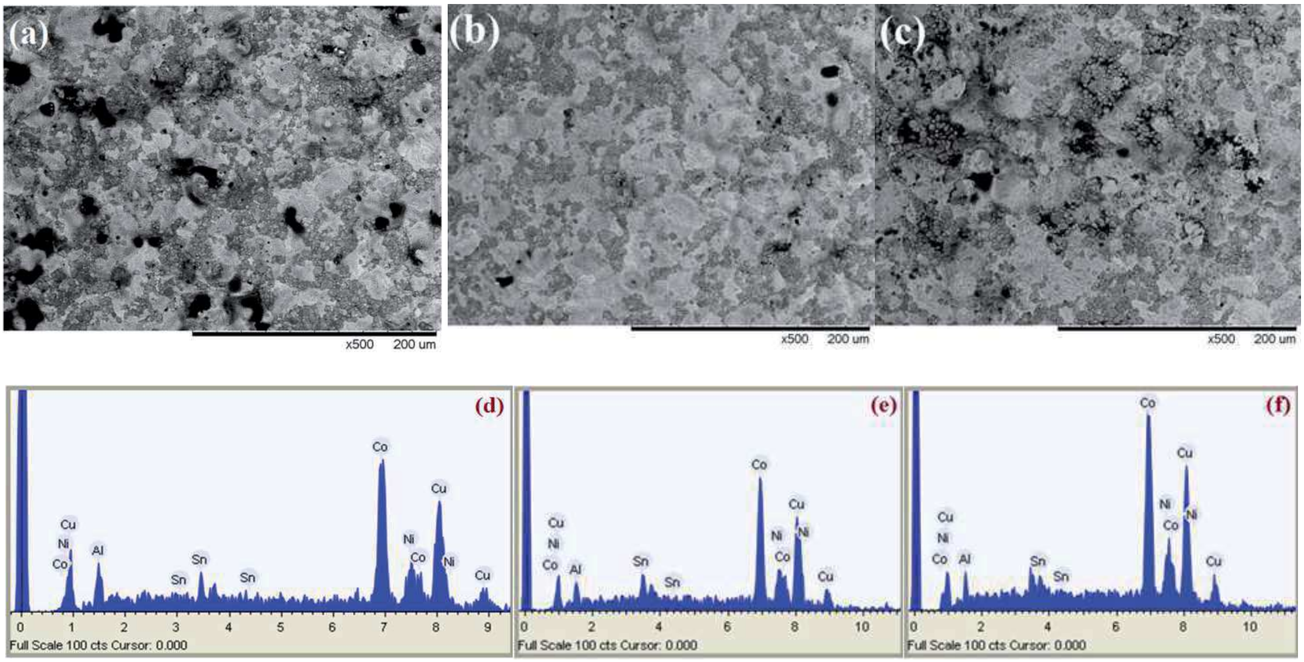


Fig. 3. SEM Microstructures of studied samples sintered at different temperature with CS method (a) 945°, (b) 960°, (c) 975° and corresponding EDS analysis of the sintered samples (d) 945°, (e) 960°, (f) 975°

Table 1 lists relative density, hardness and compression strength of the samples investigated. The highest mechanical results (density, hardness and compressive strength) were obtained at studied samples sintered with SPS method. According to the mechanical test results of CS samples, 960°C sintering temperature is suitable among the studied temperature range. There was a peak point for the all results at this temperature. When the sintering temperature was increased or decreased, the values of the samples were decreased. The elevated peak intensities of the Co_3Sn_2 intermetallic phase gives rise to mechanical properties of studied samples sintered with SPS method and sintered with CS method at 960°C as seen in Figure 1. At the same time, the porosities of these samples were lower than the sintered with CS method at 945 and 975°C as seen in Figures 2 and 3.

Table 1.
Relative density, hardness and compressive strength of the samples after sintering with different methods

Samples' sintering methods	Sintering temperature, °C	Relative density, %	Hardness, HRB	Compressive strength, MPa
SPS	900	100	98±0.6	1057.7±3
CS	945	92.9	75±1.2	1033±3
CS	960	98.4	90±1.7	1049.8±1.2
CS	975	91.6	70±1.3	996.9±2

Figure 4 shows the wear test results. The abrasion wear tests were performed with the samples SPS and within CS samples sintered at 960°C due to the having the best mechanical and mictostructure properties. As seen in Figure 4, the relative wear resistance of the SPS sample is higher about 10% than that of CS sample. However, it is known that optimization of wear rates of diamond and the matrix in a diamond containing cutting tool is necessary for a better cutting performance. Therefore it is expected that a softer matrix of CS sample may result in better cutting performance due to reduced abrasion resistance.

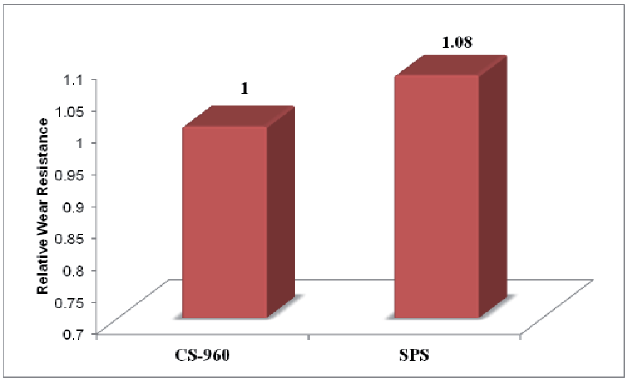


Fig. 4. The wear resistance of the SPS sample and CS sample sintered at 960°

4. Conclusions

Following results can be drawn from the present study:

- The highest relative density, the highest compressive strength and the highest hardness values are obtained in the sample sintered with SPS method.
- For CS sintering method, the optimum sintering temperature are determined 960°C. At this temperature, the all values (density, hardness and compressive strength) of the sample are closed to the SPS sintering method.
- The presence of Co_3Sn_2 intermetallic phase give rise to mechanical properties and the mechanical properties of the samples increased with the increasing amount of this phase.
- The wear resistance of the sample sintered with CS method at 960°C is lower than the sintered sample with SPS method. It is expected that softer matrix may result better cutting performance due to reduced abrasion resistance of matrix.
- The cutting performance of the diamond beads produced by using the matrix materials studied are now under investigation by cutting marble in an on-site field cutting operations.

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